Using Ecological Momentary Assessment (EMA) to Study the Impact of Colored Glasses on Sleep Quality, Energy Level, and Mood

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Spring 2016

A thesis presented to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the Bachelor of Science degree with Honors in Psychology & Neuroscience.

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Acknowledgements

I would like to thank my advisor, Dr. Eric Youngstrom, for his guidance, patience, and support, and for helping me become a better writer, planner, thinker, and student. I would also like to extend my thanks to co-investigator Dr. Nisha Gottfredson, for providing continuing consultation, resources, and mentorship, and for serving on my Honors committee. Tate Halverson has also been instrumental in helping me with this project- I greatly appreciate her valuable suggestions, advisement, and help with analyses. I would also like to thank the members of the MECCA lab, past and present, for jumping in whenever needed- I've learned so much from all of you. Finally, I would like to thank my parents, Dr. Matthew and Polly Freeman, whose encouragement has been constant and unfaltering over the years. This research was funded in part by a Summer Undergraduate Research Fellowship from the Office of Undergraduate Research at UNC-Chapel Hill, and by a Tom and Elizabeth Long Research Fellowship Award from Honors Carolina at UNC-Chapel Hill.

Abstract

The connection between sleep disturbance and mood dysregulation is a current point of interest in the field. The circadian rhythm system, which influences both sleep and mood, is itself influenced by a variety of internal and external factors, one of which is light. Light manipulation is a low-cost, non-invasive possibility for improving sleep and mood disturbances; blocking blue wavelengths of light with amber-tinted glasses has been shown to improve sleep quality, energy levels and mood. However, methods historically employed in studying sleep and mood are limited in that assessments are generally given once per day, and may not give a complete picture as to how well these interventions work. The present study used ecological momentary assessment (EMA) to assess responsiveness to amber glasses (and blue lensed control glasses) four times a day. Using a randomized crossover design, 38 participants at the University of North Carolina at Chapel Hill were assigned to starting condition and wore colored glasses three hours before bed for 12 of the 18 days of the study. Overall, the results did not support the hypothesis that the amber glasses condition would improve sleep quality, energy, and mood: on some outcome measures (sleep quality, energy level, positive affect), amber glasses steadily increased sleep quality over the course of the condition, but this effect was also seen in the blue glasses control condition. Future studies should include a washout period between conditions, a larger, more diverse sample, more objective measures of sleep, and other colors of potential control lenses.

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Sleep disturbance and circadian rhythm dysregulation have been linked with a number of psychiatric diagnoses, including affective disorders, anxiety disorders, dementia, and schizophrenia, as well as other health problems, like cardiovascular disease, cancer, obesity, and diabetes (Harvey, Murray, Chandler, & Soehner, 2011; Zelinski, Deibel, & McDonald, 2014). This could be due to the interactions between the biochemical pathways associated with rhythm generation and those associated with mood, anxiety, and health (Zelinski et al., 2014). Luckily, promising cost-effective interventions are being studied to help improve sleep hygiene and overall functioning. Light manipulation, in particular, is currently a point of interest in the field, as blocking certain wavelengths of light can help improve sleep latency and duration, as well as subsequent reported energy levels and mood (Burkhart & Phelps, 2009). However, methods historically employed in studying sleep and mood are limited in that assessments are generally given once per day, and may not give a complete picture as to how well these interventions work. This introduction will describe the potential biological mechanisms of the link between mood and sleep related outcomes, describe the manipulated light intervention and the theory behind it, and will critique the historic sleep diary method of assessment, offering ecological momentary assessment (EMA) as an alternative.

Mechanisms Common in Sleep Disturbance and Mood Disturbance

The suprachiasmatic nucleus (SCN), located in the anterior portion of the hypothalamus, serves as the master pacemaker in humans. It is capable of oscillating rhythmically (in an approximate 24-hour pattern) without the presence of environmental cues, but it is influenced by external and internal environmental inputs (Zelinski et al., 2014). Such inputs can help the SCN determine or interpret the time of day. Light, which arrives at the SCN from light-sensitive retinal ganglion cells expressing the photoreceptor melanopsin, exerts the strongest influence on the SCN, but neurotransmitters and hormones can also elicit effects on the SCN, as well as subsequent circadian rhythm and mood.

For instance, the neurotransmitter serotonin is associated with both circadian rhythm and mood. Polymorphisms of serotonin transport genes have been linked with bipolar disorder and unipolar depression, and dysfunction of the serotonergic system contributes to current etiological theories of mood disorders (among others) (Harvey et al., 2011). The SCN contains a dense serotonergic plexus, denser than many other areas of the brain (Harvey et al., 2011). Serotonin acts on the SCN to enhance its overall stability in setting circadian rhythm, and the SCN also oversees the synthesis of serotonin into its derivative, melatonin (a circadian rhythm hormone) (Harvey et al., 2011). Interestingly, lack of sleep and disruption in circadian rhythm can induce changes in the serotonergic system that are similar to those seen in unipolar depression, mainly that serotonin receptors become less sensitive to serotonin itself (Harvey et al., 2011).

There is also a link between the circadian rhythm system and the dopaminergic system. The dopaminergic system, involved with reward activation, has been implicated in a wide variety of psychiatric disorders, including mood disorders. Changes in this pathway may help explain anhedonia in depressed patients, and its interaction with the serotonergic system is important for psychopathology of mood disorders (Harvey et al., 2011). Furthermore, reward activation and the dopaminergic system is moderated by circadian rhythm: mice that have a mutated Clock gene show increased dopamine activity and behaviors indicative of mania, including hyperactivity and decreased need for sleep (Harvey et al., 2011).

Interventions for Sleep and Mood Improvement

For those who are struggling with mood or sleep problems, self-medication with alcohol or sleep medications is a relatively common option, but not an ideal one, as they can cause cognitive impairment, tolerance and dependence, and potential physical harm (Johnson, Roehrs, Roth, & Breslau, 1998; Rosenberg, 2006). Luckily, there are treatments for insomnia and mood symptoms that do not necessarily involve drugs or alcohol. Although it was previously described that sleep and circadian rhythm dysregulation are linked with serotonergic and dopaminergic functioning, in which dysfunction is usually treated with drugs, improvements in the neurobiology of the circadian system can be made non-pharmacologically (Harvey et al., 2011). For instance, Cognitive Behavioral Therapy for Insomnia (CBT-I) is generally effective in treating primary insomnia (Taylor & Pruiksma, 2014). Interpersonal and social rhythm therapy (Frank, 2007) and light therapy (Gottlieb & Terman, 2012) are also good candidates for improving sleep hygiene and mood symptoms. Social rhythm therapy involves maintaining stability in activity and social rhythms, and is shown to be effective in treating patients with bipolar disorder (Frank, 2007). Historically, bright light exposure has been used to treat patients with unipolar depression (with a seasonal pattern; Golden et al., 2005), and light restriction has been used for patients in a manic episode of bipolar disorder (Barbini et al., 2005). However, such treatments are not always feasible for patients, who would have to be willing to stay in complete darkness hours beyond when they would normally be asleep (Burkhart & Phelps, 2009).

Another possible intervention strategy hinges on the fact that the photoreceptor melanopsin, which sends signals about light to the SCN, only responds to relatively short wavelengths of light (<550 nm), corresponding to the blue and blue-green portions of the visible light spectrum (Burkhart & Phelps, 2009). Therefore, blue light has the strongest influence on signaling to the SCN and impacting circadian rhythm, as it signals for the SCN to suppress melatonin synthesis (Sasseville, Paquet, Sevigny, & Hebert, 2006). Theoretically, filtering out the blue wavelengths of light would essentially be the same as staying in complete darkness (as blocking the blue wavelengths of light would trigger the release of melatonin from the pineal gland), and could be a more feasible treatment than total darkness therapy (Sasseville et al., 2006). Wearing amber-tinted glasses to filter out blue light emitted from artificial light sources in the evening would allow patients to participate in normal evening activities, rather than needing to stay in complete darkness. This type of intervention has been shown to improve sleep in patients with mood disorders, and in individuals who self-reported as having sleep difficulty (sleep-onset insomnia, mid-sleep insomnia, or terminal insomnia) (Henriksen et al., 2014; Burkhart & Phelps, 2009). Such glasses have also been shown to preserve high levels of melatonin production, similar to the level of melatonin produced in constant dim light (Kayumov et al., 2005). In studies investigating the effects of blocking blue light in the evening, participants were instructed to wear the glasses three hours before their target bedtime; after 2 weeks wearing the glasses, those in the amber glasses condition had significantly better self-reported sleep quality and significantly higher scores on a measure of positive affect, as compared to a control condition who wore yellow-tinted glasses that blocked ultra-violet light (Burkhart & Phelps, 2009). Such an intervention is promising to treat sleep disturbances and mood problems, as the amber glasses pose little to no risk, are easily accessible, and are inexpensive.

Using Ecological Momentary Assessment to Study Sleep and Mood

There are some drawbacks in the historic methodology of studying sleep and mood, however. For instance, many studies assessing interventions targeted to improve aspects of sleep and affect rely on subjective measures of energy, mood, and sleep quality (Burkhart & Phelps, 2009; Kayumov et al., 2005). These types of measures are limited in that participants may not be able to accurately self-identify and report on their energy levels or moods. Reporting in such a way may be especially difficult when using self-reported “sleep diaries,” in which participants code what time they went to bed, what time they woke up, their energy levels, and their perceived sleep quality. In the studies described above, participants were instructed to fill out the sleep diaries either the in the morning after they woke up (Burkhart & Phelps, 2009), or at night coding for the previous night’s sleep (Kayumov et al., 2005). In filling out the diaries this way, participants may not be able to accurately remember how they slept, or may realize that their energy levels changed throughout the day. Memories may be distorted, and the dynamic nature of energy and mood may not be best reflected in a single self-report measure or sleep diary for each day.

Ecological momentary assessment (EMA) may help combat these problems that arise when using sleep diaries or other self-report measures that rely on memory recall. EMA is a method for collecting data in real-time, and in a variety of conditions throughout a day (Miller, Kyle, Marshall, & Espie, 2013). It allows researchers to inquire about symptoms at the moment, rather than retrospectively, and in the environmental context in which they occur, which is beneficial when studying dynamic topics, such as energy levels and mood. EMA also employs frequent sampling, which when combined and analyzed together, can give a more complete assessment of symptoms throughout a single day and over longer spans of time (Levitt et al., 2004).

A major benefit of using EMA is that it avoids the reliance on retrospective accounts of symptoms. Studies have shown that participants often overestimate positive emotions and underestimate negative ones in a retrospective account, when compared to using EMA to assess emotions over a 24-hr period (Ebner-Priemer & Trull, 2009). Other cognitive biases can occur in retrospective accounts as well: due to an increased cognitive load resulting from thinking of symptoms over time, participants may be influenced by the personal heuristics effect (reporting experiences more personally relevant to their normal state), the salience or novelty effect (reporting experiences that seem unusual and stand out), or the mood-congruent memory effect (reporting experiences that are consistent with their current state and ignoring other experiences) (Trull & Ebner-Priemer, 2009). In contrast, EMA allows participants to answer questions about themselves without increasing cognitive load (i.e. "To what extent are you feeling fatigued *right now?*"), and therefore reduces potential recall biases (Trull & Ebner-Priemer, 2009).

EMA also allows researchers to assess the context in which certain symptoms occur. In many retrospective accounts, the focus is the symptom over a given amount of time (possibly over the past week, month, or year), but not in specific situations (e.g. while alone, while doing strenuous physical activities, while with others, while in stressful situations, etc.) (Ebner-Priemer & Trull, 2009). The potential interaction between the symptom and the context in which it occurs could provide valuable insight into the processes involved in the topic of study.

Another general advantage of using EMA over a retrospective measure of analysis is that EMA assesses symptoms in real-life situations, and can therefore be generalized to a greater extent (Ebner-Priemer & Trull, 2009). In theory, studying symptoms as they occur in their natural environment, rather than in a laboratory setting, can help researchers draw broader conclusions, and it helps raise external and ecological validity. However, it is important to note that there have not been any large-scale empirical studies that support the idea that an EMA design shows increased external validity over laboratory designs (Ebner-Priemer & Trull, 2009).

Future studies are needed to further evaluate the validity of data from projects using an EMA design (Ebner-Priemer & Trull, 2009). Furthermore, it is important to recognize that an inadequate or inappropriate research design (e.g. not choosing thoughtful items for EMA surveys/diaries or using a time sampling design that is not appropriate for your variables of interest) within an EMA study could threaten overall validity (Ebner-Priemer & Trull, 2009).

The Present Study: Using EMA to Assess Response to Amber Glasses

EMA has specific benefits in studying topics such as sleep/energy levels and mood, or in evaluating certain interventions, like the amber-tinted glasses. First of all, EMA can more readily assess dynamic processes and identify variability in symptoms more than a single retrospective account could. Moods and levels of daytime sleepiness are continuously expressed throughout the day, so they are subject to great levels of variability. Therefore, using an EMA approach with higher temporal resolution (i.e. taking measurements at multiple time points throughout the day) would be beneficial in order to get a sense of this variability (Ebner-Priemer & Trull, 2009).

The present study used an EMA approach to more thoroughly assess the effectiveness of amber-tinted glasses targeted to improve sleep duration and quality, with sleep and mood-related measures taken at four time points each day. We hypothesized that, when wearing amber glasses, participants will report more improved overall sleep quality and mood (i.e. increased positive affect and decreased negative affect) than when wearing blue-lensed control glasses, as well as compared to baseline (no glasses). We also hypothesized that, when wearing amber glasses, participants will report lower energy earlier in the evening (corresponding to increased melatonin release) compared to wearing blue glasses or no glasses, as well as higher energy earlier in the morning (due to increased sleep quality) compared to wearing blue glasses or no glasses. We hypothesized that these relationships would hold true, even when controlling for morning/ evening preference.

Method

Participants

39 participants from the University of North Carolina at Chapel Hill (students, staff, or faculty) were recruited through fliers and through online postings. These postings were targeted toward the general campus population, as well as toward a specific service organization. Those recruited from the service organization were offered their choice of 40 service hours or $40 as compensation upon completion of the study; general campus volunteers received $40 as compensation.

Volunteers indicated their interest through email. Demographic information is listed in Table 1. Exclusion criteria included being younger than 18 years of age or older than 50 years of age, as well as not having a smartphone with text and email capabilities.

Measures and Materials

Chronotype (i.e. Morningness-Eveningness Preference). The Student Morningness-Eveningness Questionnaire (SMEQ) (Košćec, Radošević-Vidaček, & Kostović, 2001) assesses the time of day that participants experience peak alertness. The measure inquires about habits over a 24-hour period. Scores for each item range from 0 to 2, with lower scores indicating a preference for morning (or that one is a "morning person") and higher scores indicating a preference for evening (or that one is a "night person"). The SMEQ has an internal consistency of .77 (Košćec et al., 2001).

State Affect. The Positive and Negative Affective Schedule (PANAS) (Watson, Clark, & Tellegen, 1988) was used to assess state affect throughout each day of the study. This measure is made up of 20 items, 10 of which correspond to positive affect (e.g. “inspired,” “alert,”, “excited”) and 10 of which correspond to negative affect (e.g. “distressed,” “upset”, “irritable”). Participants rate the degree to which they feel that way at the moment from 1 (*Very slightly or not at all*) to 5 (*Extremely*). Higher scores indicate a higher level of positive affect or negative affect. The Cronbach's alpha is .90 for positive affect and .87 for negative affect (Watson et al., 1988).

Sleepiness and Energy. The Stanford Sleepiness Scale (SSS) (Hoddes, Dement, & Zarcone, 1972) was included on the daily surveys and was used to assess present sleepiness. It is a one-item measure that uses a scale rating from 1 to 7 that corresponds to different degrees of sleepiness, with higher scores indicating a higher degree of sleepiness. Participants also responded to a separate question where they rated their present energy level on a scale from 0 (*Very low, exhausted*) to 5 (*Excellent energy*).

Factors Affecting Sleep. Other EMA items. Other items were included on the daily surveys so that they could be used in lieu of single-time point, retrospectively assessed sleep diaries. Participants were asked if they had consumed caffeine since the previous survey (and if so, how much), if they had consumed alcohol since the previous survey (and if so, how much), if they had exercised since the previous survey (and if so, for how long), and if they had eaten since the previous survey (and if so, if it was a meal or a snack). The first survey of the day also asked participants to rate their sleep quality from the previous night on a scale from 1 (*Very bad*) to 5 (*Very good*) and how many hours they slept. The first survey also asked participants what time they put on the glasses the previous night, if applicable.

Objective Measure of Sleep. GENEActiv accelerometer watches produced by ActivInsight Ltd. were used as an objective measure of sleep efficiency. These watches were given to a random subset of participants, who wore them throughout the entire study on their non-dominant wrist. The GENEActiv watches are waterproof and non-intrusive (with dimensions of 43mm x 40mm x 13mm), making them suitable for continuous 24-hour wear. They measure skin temperature and produce a measure of sleep efficiency for each night of wear.

Colored Lenses. Participants wore Uvex Skyper Anti-Fog Safety Glasses with blue lenses (S1932X) and with amber lenses (S1933X) over the course of the study. Participants were randomized to starting color, and then switched to wearing the other color after 6 days. Figure 2 shows the light transmittance of each type of glasses. We chose this particular model of glasses because the amber ones block a large percentage (>90%) of blue light from reaching the eye, larger than the percentage blocked from other models of amber glasses. We used blue glasses as control lenses to account for the potential placebo effect of simply wearing a pair of lenses. The blue color was chosen because it blocks a similar percentage of light from entering the eye, the opposite wavelengths than the amber ones do. Participants were asked to wear these glasses approximately three hours before their normal bedtime.

Procedure

Participants responded to recruitment advertisements through email to schedule an in-person meeting to review the consent form. Groups of participants were run in bursts over the course of four months to ensure there were sufficient materials available. Participants also completed a baseline SMEQ and a baseline demographics survey at this meeting.

All participants began Day 1 of the study on a Saturday, to control for potential weekday/ weekend effects. For Days 1-6 of the study, participants completed baseline measures on the PANAS, the SSS, and the other sleep items on the EMA surveys. Four text messages (or emails, if the text messages did not work for the participants' cell phone service provider) containing the

Qualtrics survey link were sent each day to the participants. The times of sending were randomized each day based on when participants reported waking up and falling asleep to ensure that the surveys would not be sent during a time they would likely be asleep. This study used signal contingent assessment, meaning that the participants were prompted to answer the survey questions when they got a new text/email alert to their phone. Participants were instructed to answer the surveys as soon as possible after receiving the message, provided that it was safe/appropriate to do so (i.e. not in class, driving, etc.).

This study employed a randomized crossover design to assign glasses condition: in addition to answering the EMA surveys, participants were randomized to wear either amber or blue glasses for Days 7-12. Participants were instructed to wear these glasses three hours prior to their normal time of sleep onset. Nightly reminders were sent to all participants three hours before their reported bedtime to prompt them to put on the glasses. Participants returned to the lab before Day 13 to pick up their second pair of glasses. For Days 13-18, participants answered the EMA surveys and wore their second pair of glasses three hours before sleep onset. To measure adherence, participants were asked to email "selfies" of themselves wearing the glasses each night. These pictures were deleted immediately upon receipt.

Some participants were also randomized to wear one of eight GENEActiv actigraphy watches, used as an objective measure of sleep quality. Participants were instructed to wear these watches on their non-dominant wrist for the entire study.

After Day 18, participants returned all materials, were debriefed, and received their compensation. There was no penalty for missed surveys or for forgetting to wear the glasses.

Results

Sample characteristics (gender, mean age, and race/ethnicity) are displayed in Table 1. One participant was excluded from analysis because of their irregular shift work schedule during the duration of the study. Additionally, two participants withdrew from participating in the study before its completion due to the time commitment it required. A total of 2692 surveys were sent out, and 2098 were answered, with a response rate of .80. A total of 15 participants were assigned to wear GENEActivs. Scores on all measures were converted to percent of maximum possible (POMP) scores. Table 2 shows the descriptive statistics for the PANAS, the SSS, the energy level item, the sleep quality item, the GENEActiv sleep efficiency estimate, and the SMEQ POMP scores.

Mixed regression models were used to test all hypotheses, with repeated measures of sleep quality, energy, and affect nested within individuals. We ran models that allowed for random intercepts and random slopes. We tested for the color of glasses, the number of days in condition, time of day (morning versus non-morning survey), chronotype, and the interactions between glasses color * day in condition, day in condition *chronotype, glasses condition * chronotype, time of day * glasses condition, and time of day * chronotype. POMP scores for sleep quality, sleep efficiency, SSS, energy level, PA, and NA were used as outcome measures. Analyses were completed with the *nlme* package in R (Pinheiro et al., 2015). The crossover effect was assessed by adding 'First Condition' as a predictor in addition to the dichotomous condition variables; when it was included, the models were over fitted, so it was omitted. The following analyses lump participants' first and second conditions together, with amber and blue conditions included as predictors, comparing outcomes to baseline as a reference.

Sleep Quality

The intercept of predicted sleep quality varied between participants, *SD* = .11, and the effect of the amber glasses condition also varied between participants over the course of the study, *SD* = .09, *ICC* = -.201. Figure 2 shows spaghetti plots of participants' change in sleep quality by condition, where the varying slopes and intercepts are evident. Figure 3 shows a panel plot by glasses condition. We ran a model predicting sleep quality using the predictors described above. The beta weights are displayed in Table 3.

The intercept for the final model was significant, indicating that for the average person, sleep quality ratings were approximately 85% of the maximum possible at the start of the study (and significantly different from 0). While allowing slopes and intercepts to vary among individuals, both amber glasses condition and blue glasses condition significantly predicted sleep quality, predicting an 18% and 13% initial decrease in sleep quality compared to baseline, respectively. However, the significant interactions between amber condition and day in condition and blue condition and day in condition indicated that as day in each condition increased, the glasses condition improves participants' sleep quality by an average of 2% and 3%, respectively. These interactions can be viewed graphically in Figures 4 and Figure 5. These show that sleep quality ratings increase up to baseline levels over the course of the condition wearing glasses (either color). This result is promising, but does not fully support the hypothesis that the amber glasses would increase overall sleep quality compared to baseline or blue glasses condition.

We conducted similar models predicting sleep efficiency obtained from the GENEActiv watches that a subset of participants wore throughout the study. Sleep efficiency is the proportion of time one is asleep during a period of time they are in bed or trying to sleep. Here, we used it as more objective estimate of sleep quality. The sleep efficiency estimate was calculated through GENEActiv macro software.

Again, intercepts varied substantially across participants, *SD* = .12, as did the random effect of the amber glasses, *SD* = .16, *ICC* = -.787 (Figure 6, Figure 7). Beta weights are displayed in Table 4. The only significant portion of this model was the interaction between blue glasses condition and chronotype, with unit increase on the SMEQ (favoring more of an evening-preference) associated with a .6% decrease in sleep quality while wearing the blue glasses, holding everything else constant. This interaction is depicted in Figure 8. Again, this did not support study hypotheses: there was not a significant main effect for amber glasses condition, and there were not significant interactions involving amber glasses condition, so the hypothesis that the amber glasses condition would improve sleep efficiency was not supported.

Energy Level

Energy level was assessed using the Stanford Sleepiness Scale, and by a rating scale of energy from 0 – 5. The model for predicted scores on the SSS will be discussed first.

Again, intercepts for predicted sleepiness scores varied between participants at baseline, *SD* = .11. The effect of the amber glasses condition on energy level also varied between participants, *SD* = .04, *ICC* = .58 (Figure 9, Figure 10). Beta weights are displayed in Table 5. There was a significant main effect for blue glasses condition on energy level, with an average of a 9.62% increase in sleepiness during the blue glasses condition phase, holding all else constant. This is inconsistent with study hypotheses, as the blue glasses condition was the control lens and was not intended to change sleepiness levels. There was also a significant negative interaction between blue glasses condition and chronotype, with evening-preference associated with a weaker effect of the blue glasses on energy level. This is depicted in Figure 11. There was also a significant interaction between day in condition and amber glasses condition, meaning that as day in amber condition increased, the effect of the amber glasses on sleepiness got stronger. This is depicted in Figure 12. The only other significant portion of the model was the interaction between day in condition and chronotype, meaning that over the course of each condition, having more of an evening-type had more of an influence on self-reported sleepiness. Overall, this model did not support study hypotheses.

We also examined predicted energy ratings. This model showed variation in intercepts, *SD* = .12, and in the random effect of the amber glasses, *SD* = .05, *ICC* = .26 (Figure 13, Figure 14). Beta weights are shown in Table 6. The intercept of this model was significant, indicating that the average person started out at 69.4% of the maximum score on energy at the start of the study. There were significant main effects for both the amber glasses and blue glasses conditions, with each being associated with an approximate 7% decrease in energy ratings. There was a significant positive interaction between the amber glasses condition and day in condition, though, with a 1.45% increase in the effect of the amber glasses on energy level for each additional day in that condition, ending with average energy ratings approaching baseline levels (Figure 15). This is a promising result, showing a linear increase of energy ratings over each day of wearing the amber glasses, but it still does not fully support the hypothesis that the amber glasses would improve overall energy levels. Furthermore, there was no significant interaction between amber glasses condition and morning versus evening survey, so the hypothesis that energy levels would be higher in the morning and lower in the evening during this condition was not supported.

There was a significant interaction between blue the blue glasses condition and chronotype, with unit increase toward evening-preference associated with a .59% increase in the effect of the blue glasses on energy level. Again, this does not support study hypotheses.

Positive Affect

There was variability in the intercepts across participants, *SD* = .12, and on the effect of the amber glasses on positive affect, *SD* = .05, *ICC* = -.04 (Figure 16, Figure 17). Beta weights for this model are displayed in Table 7. The intercept of this mixed model was significant, indicating that on average, participants started off the study responding at 40.95% of the maximum possible score for positive affect, holding all else constant. There were also significant main effects for both amber glasses condition and blue glasses condition, with each associated with an initial 11.51% and a 7.16% decrease in positive affect from baseline, respectively. There were significant positive interactions between each glasses condition and day in condition, though, meaning that participants' scores on positive affect increased at a faster rate over the course of the time in each condition, eventually ending up with average positive affect scores similar to baseline levels at the end of each condition. These interactions are shown in Figures 18 and 19. There was a significant general main effect for day in condition predicting positive affect, also associated with a decrease from baseline. Finally, there was as significant main effect for morning versus evening survey, with the morning survey being associated with higher positive affect scores compared to baseline, holding all else constant.

Negative Affect

Finally, we examined models predicting negative affect. There was little variation in intercepts across participants, *SD* = .04, and in random effect of the glasses across participants, *SD* = .02, *ICC* = -.12 (Figure 20, Figure 21). Beta weights for this model are displayed in Table 8. The intercept was significant for this model, indicating that on average, participants started the study at 3.61% of the maximum possible negative affect score. The only other significant portions in this model were the interactions between amber glasses condition and day in condition and between blue glasses condition and day in condition. Each was associated with a steeper increase in negative affect scores as days continued in each condition (Figures 22 and 23).

Discussion

We hypothesized that the amber glasses condition would be associated with improved overall sleep quality (higher scores on self reported sleep quality and higher sleep efficiency estimates from the GENEActivs) and positive mood (increased positive affect on the PANAS), and decreased negative mood (lower scores on negative affect items on the PANAS). Most of the observed results do not support the first hypotheses: on some outcomes, the amber glasses condition did not have much of an impact, and on others both the experimental and control conditions showed an effect. Our second hypothesis that the amber glasses condition would be associated with higher energy levels in the morning and lower energy levels in the evening was not supported by study results. There was an unexpected main effect for time of day on positive affect ratings, however, irrespective of chronotype and glasses condition.

Overall, some portions of the results are promising, however: sleep quality and energy level increased over the course of wearing the amber glasses, but it is important to note that the effect occurred during the blue glasses condition as well for predicting sleep quality. This could have been due to placebo effect of wearing any pair of lenses, or perhaps the blue lenses had some sort of additional effect on sleep quality and energy ratings. Participants may have expected the blue lenses to cause a change on outcomes, or perhaps the flooding of blue light/ blocking of orange light at night causes some kind of unexpected physiological effect related to sleep quality and subsequent energy/mood. Use of another color of control lens would be beneficial in future studies.

Perhaps the biggest limitation of this study is the lack of a washout period between glasses conditions: the effects of one glasses condition could have carried into the other condition, impacting results. Future studies could be conducted over a longer time period, allowing several days in between the glasses conditions. Other limitations include the large amount of females in the sample, and the lack of racial/ ethnic diversity. Larger, more diverse samples would be more beneficial. Furthermore, circadian rhythms fluctuate along the menstrual cycle (Baker & Driver, 2007), which could have caused differential responses in females, depending on their stage in the menstrual cycle at the time of the study. There were not strict exclusion criteria, as the researchers aimed to investigate the effects of the glasses in a broader, "real-world" sample, but this may have decreased internal validity and made confounding effects more likely. Another limitation includes the use of a non-clinical sample. There were floor/ceiling effects on some of the outcome measures (i.e. participants started the study with relatively high sleep quality and relatively low negative affect, for example), which could have made it less likely to detect changes in outcome that might have occurred. It also minimized the possible therapeutic effect of the glasses, if participants already scored well on the measures at baseline. Investigating the use of the glasses in a sample of individuals concerned with their sleep or mood at baseline would be a beneficial next step.

It is important to note that these models only investigated the linear relationships between variables. Future analyses could investigate if there is a curvilinear effect of the glasses over time on these outcome measures. Other future studies could look at the possible moderating effects of race, gender, and age on responsiveness to the glasses. Furthermore, future studies could consider taking melatonin samples to measure physiological changes, and could study potential genetic differences between responders to the glasses and non-responders. Finally, parsing out weekend days versus weekdays could provide further insight in the future about how sleep quality, energy, and mood naturally change throughout the week, and how they might change differentially while wearing the glasses.

To conclude, the study did not yield completely expected results and did not fully support our hypotheses that wearing amber-tinted glasses could improve sleep quality and mood and increase morning energy. However, these results do not completely rule out the possibility that these glasses could be an effective therapeutic tool to improve sleep and mood related outcomes. Future studies with a larger, more diverse sample, and more improved methodology could yield different results, which may one day help people with sleep or mood concerns.

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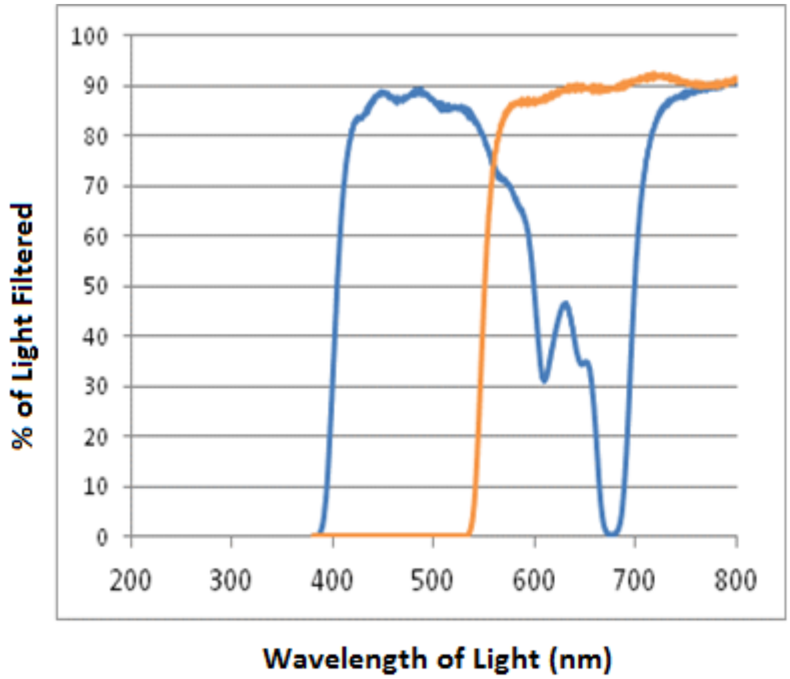

Figure 1. Light transmittance for blue and amber lenses. Peak wavelength for melatonin suppression is ~446-477 nm.

Table 1.

Sample Characteristics

	Male (n)	Female (n)	Age (M)	Age (SD)	Caucasian (n)	Asian American (n)	African American (n)	Hispanic (n)
Overall	6	33	21.97	3.74	24	10	3	2

Table 2.
Descriptive Statistics of Sleep Quality, GENEActiv Sleep Efficiency, SSS, Energy, and PANAS

	N	Mean	*SD*	Min	Max
Sleep Quality POMP	566	.67	.24	0	1
Sleep Efficiency POMP	758	.71	.21	.05	1
SSS POMP	1996	.27	.24	0	1
Energy POMP	1993	.64	.24	0	1
Positive Affect POMP	1955	.28	.19	0	.95
Negative Affect POMP	1960	.05	.08	0	.65

Note: POMP = Percent of Maximum Possible; SSS = Stanford Sleepiness Scale; PANAS = Positive and Negative Affective Schedule

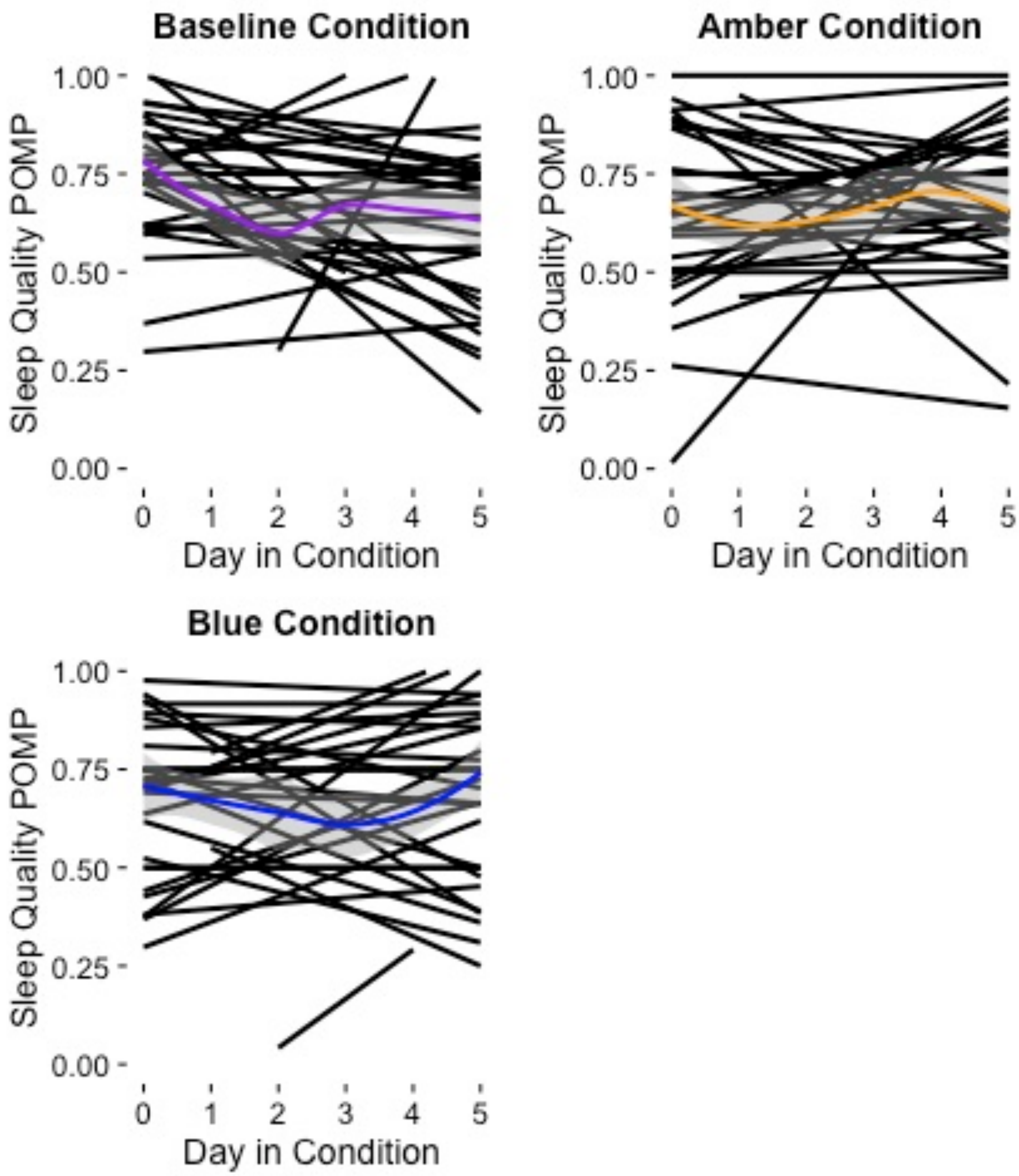

Figure 2. Spaghetti plot of linear trends within person for sleep quality (POMP), split by glasses condition

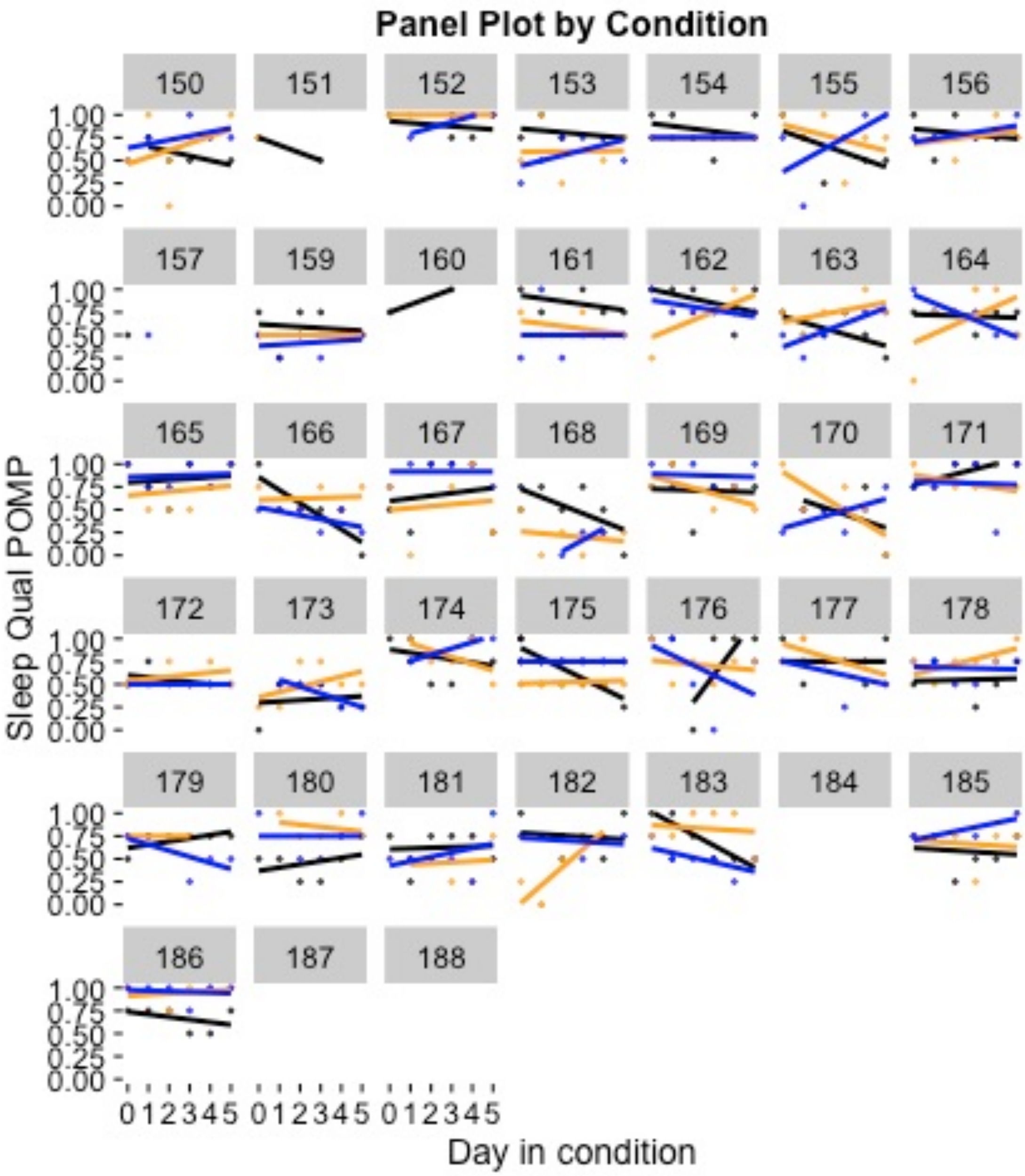

Figure 3. Panel plot of individual data for sleep quality.

Table 3.

Beta Weights for Model Predicting Self Reported Sleep Quality POMP Scores

Predictor	*ß*	*S.E.*	*DF*	*t*	*p*
Intercept	.85	.07	522	12.15	<.0001
Amber condition (0,1)	-.18	.07	522	-2.49	.01
Blue condition (0, 1)	-.13	.06	522	-2.12	.04
Day in condition (0,6)	-.02	.01	522	-1.21	.23
SMEQ POMP	-.01	.01	33	-1.81	.08
Amber condition * day in condition	.03	.01	522	2.50	.01
Blue condition * day in condition	.03	.01	522	2.27	.02
Day in condition * SMEQ POMP	-0.001	.001	522	-.81	.42
Amber condition * SMEQ POMP	.01	.01	522	1.61	.11
Blue condition * SMEQ POMP	.01	.004	522	1.16	.25

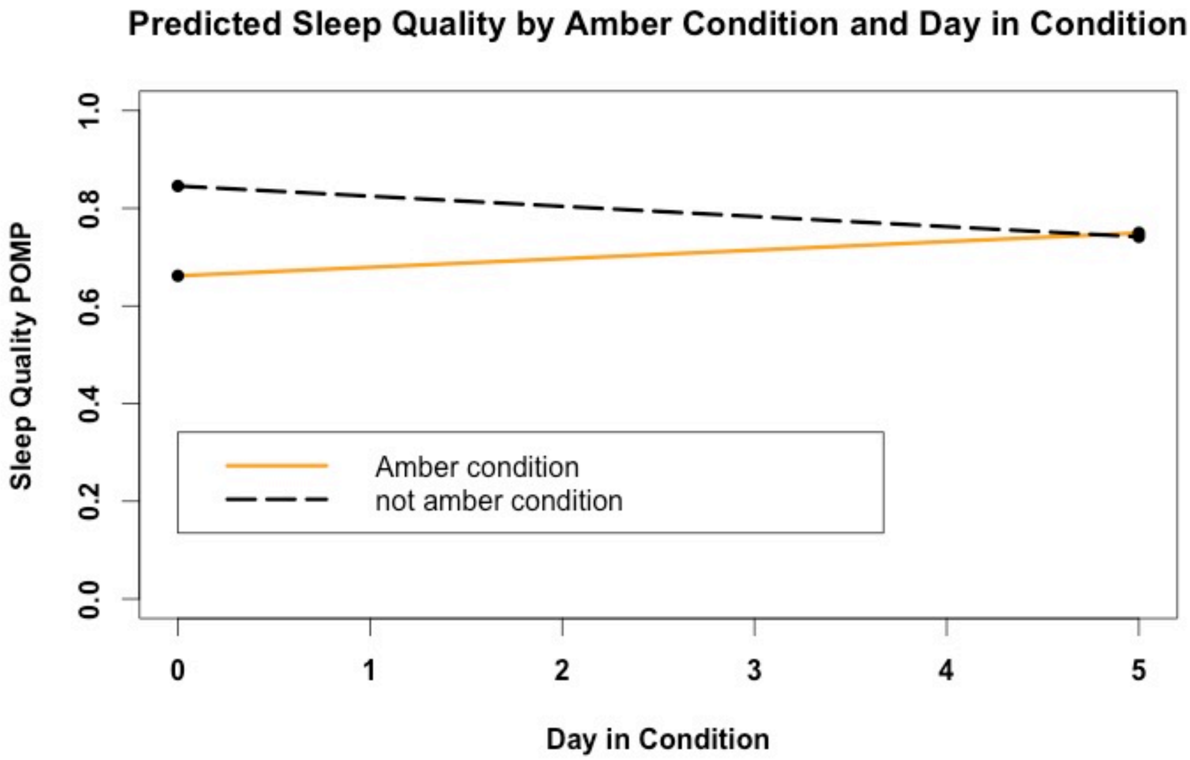

Figure 4. Interaction between amber condition (yes/no) and day in condition on sleep quality ratings.

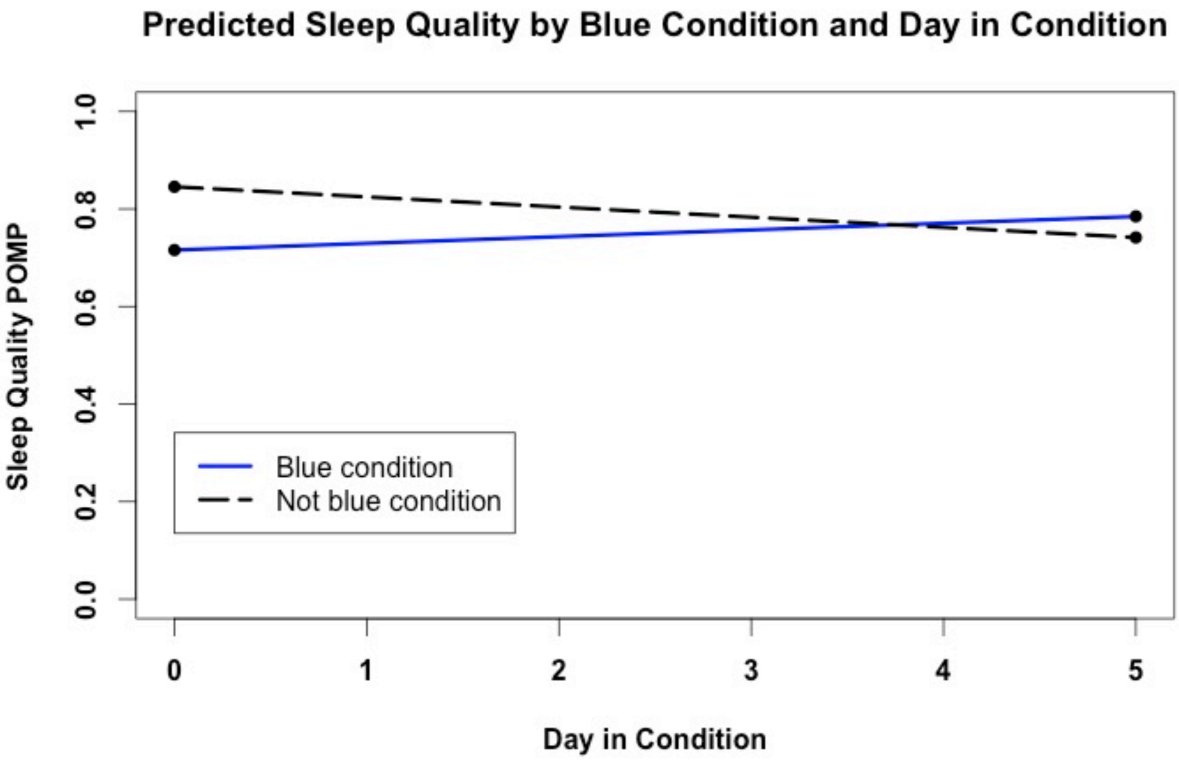

Figure 5. Interaction between blue condition (yes/no) and day in condition on sleep quality ratings.

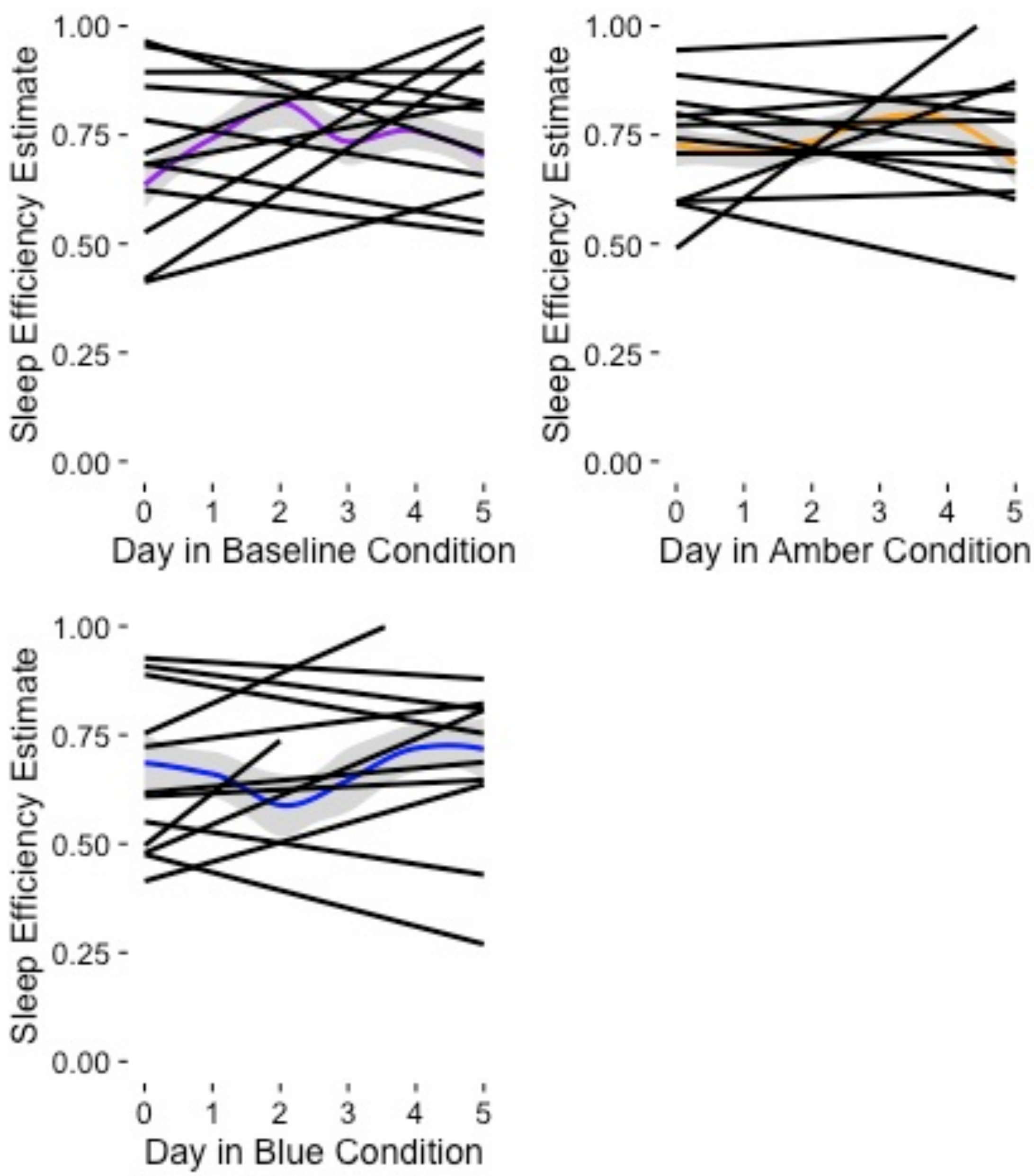

Figure 6. Spaghetti plot of linear trends within person for sleep efficiency (GENEActivs), split by glasses color.

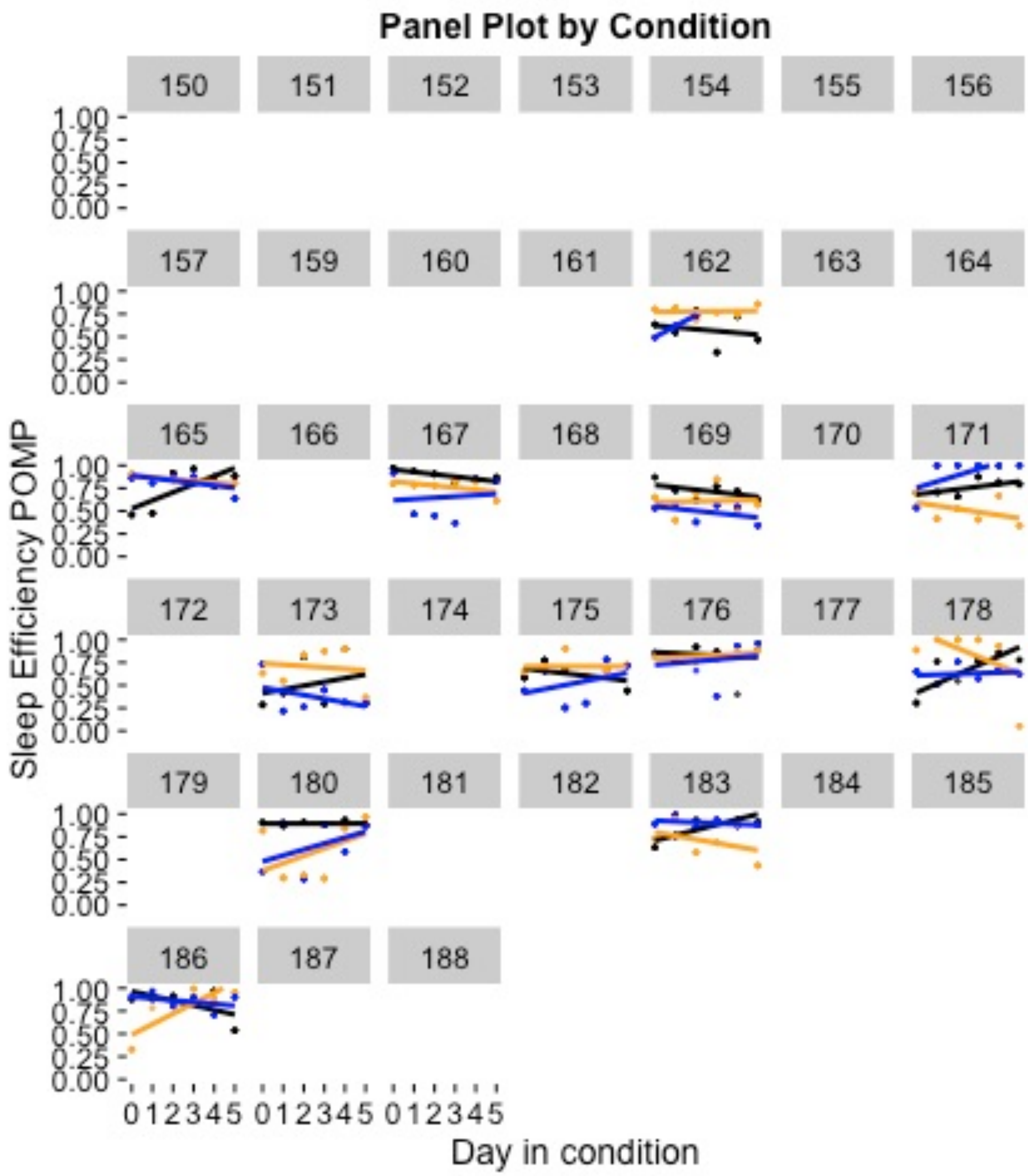

Figure 7. Panel plot of individual data for sleep efficiency (GENEActivs).

Table 4.

Beta Weights for Model Predicting GENEActiv Sleep Efficiency Estimate (POMP)

Predictor	*ß*	*S.E.*	*DF*	*t*	*p*
Intercept	.76	.08	738	10.08	<.0001
Amber condition (0,1)	-.02	.10	738	-.24	.81
Blue condition (0, 1)	.01	.04	738	.34	.74
Day in condition (0,6)	.003	.01	738	.36	.72
SMEQ POMP	-.01	.01	10	-.86	.41
Amber condition * day in condition	-.01	.01	738	-1.70	.09
Blue condition * day in condition	-.005	.01	738	-.54	.59
Day in condition * SMEQ POMP	.001	.001	738	1.71	.09
Amber condition * SMEQ POMP	.005	.01	738	.55	.58
Blue condition * SMEQ POMP	-.01	.002	738	-2.39	.02

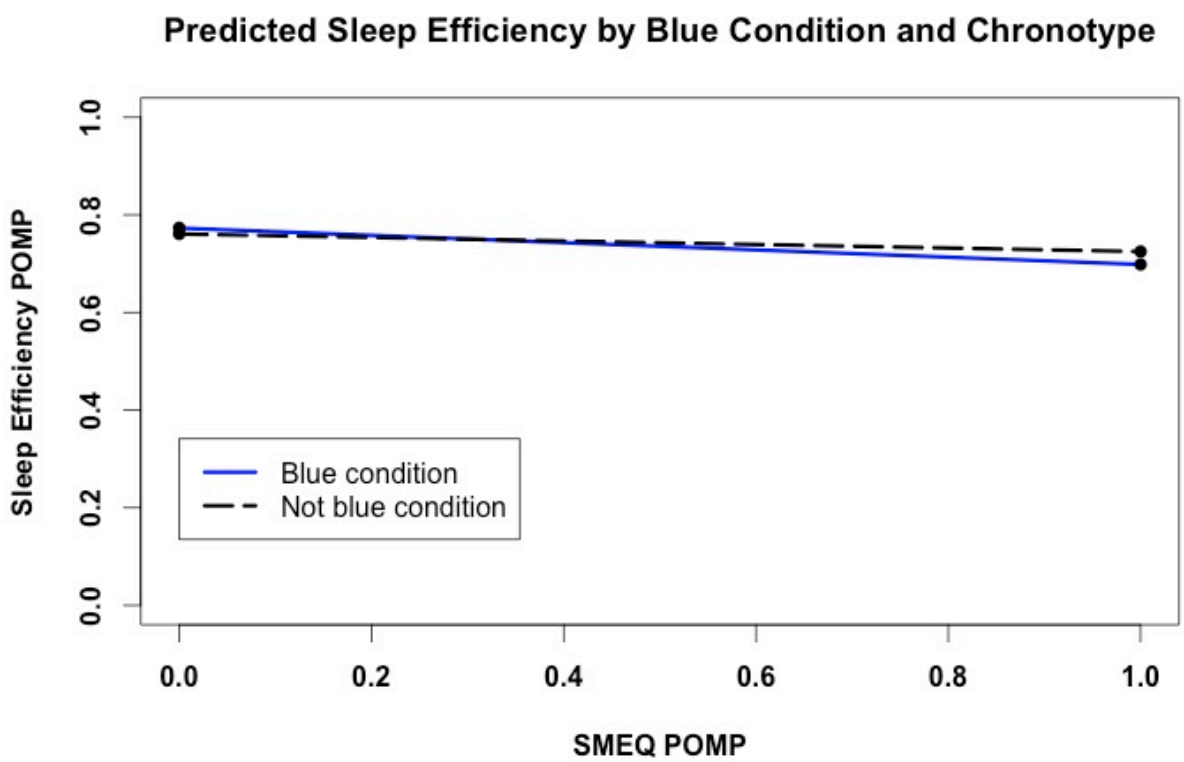

Figure 8. Interaction between blue condition (yes/no) and chronotype on sleep efficiency estimate.

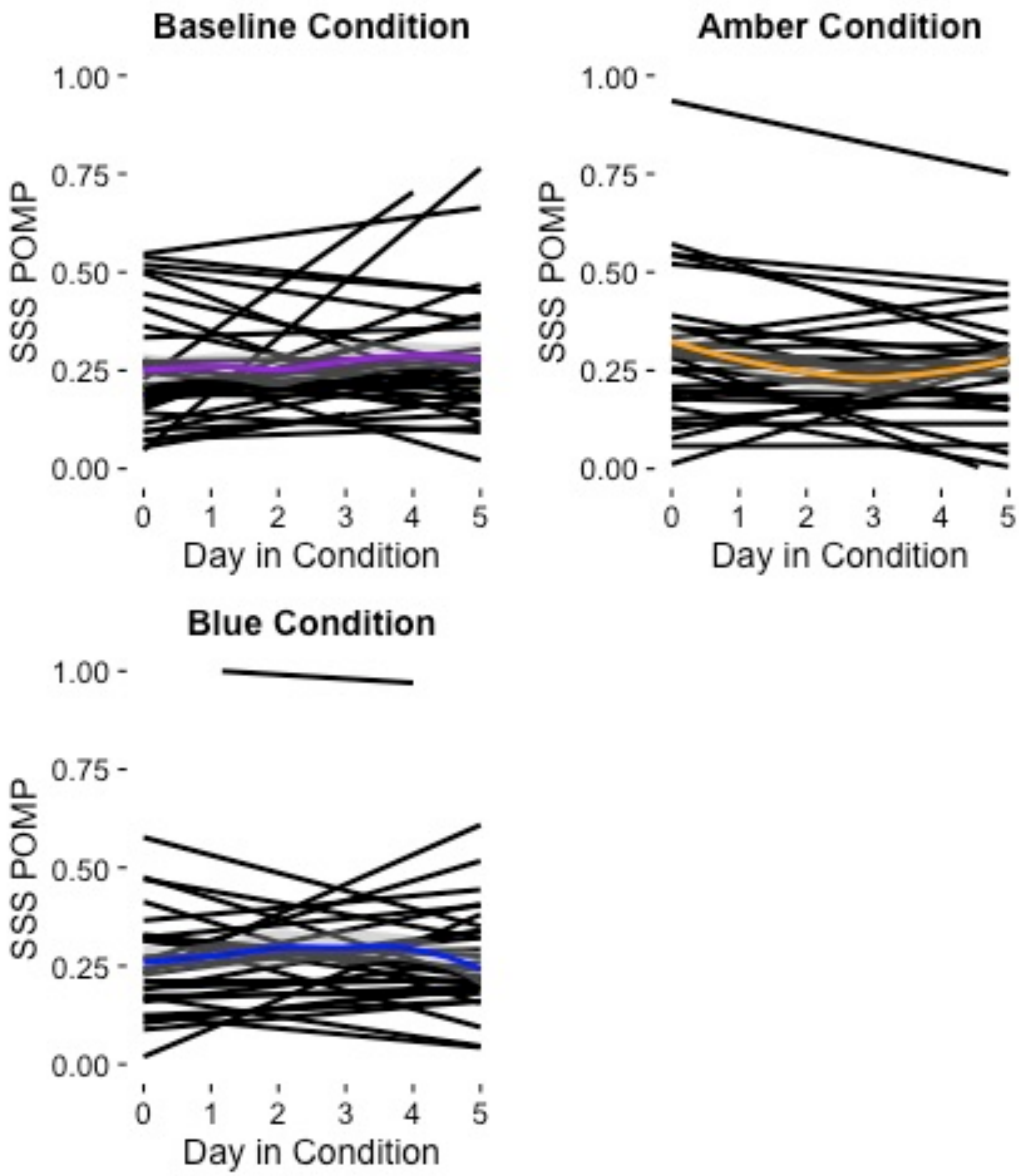

Figure 9. Spaghetti plot of linear trends within person for scores on Stanford Sleepiness Scale.

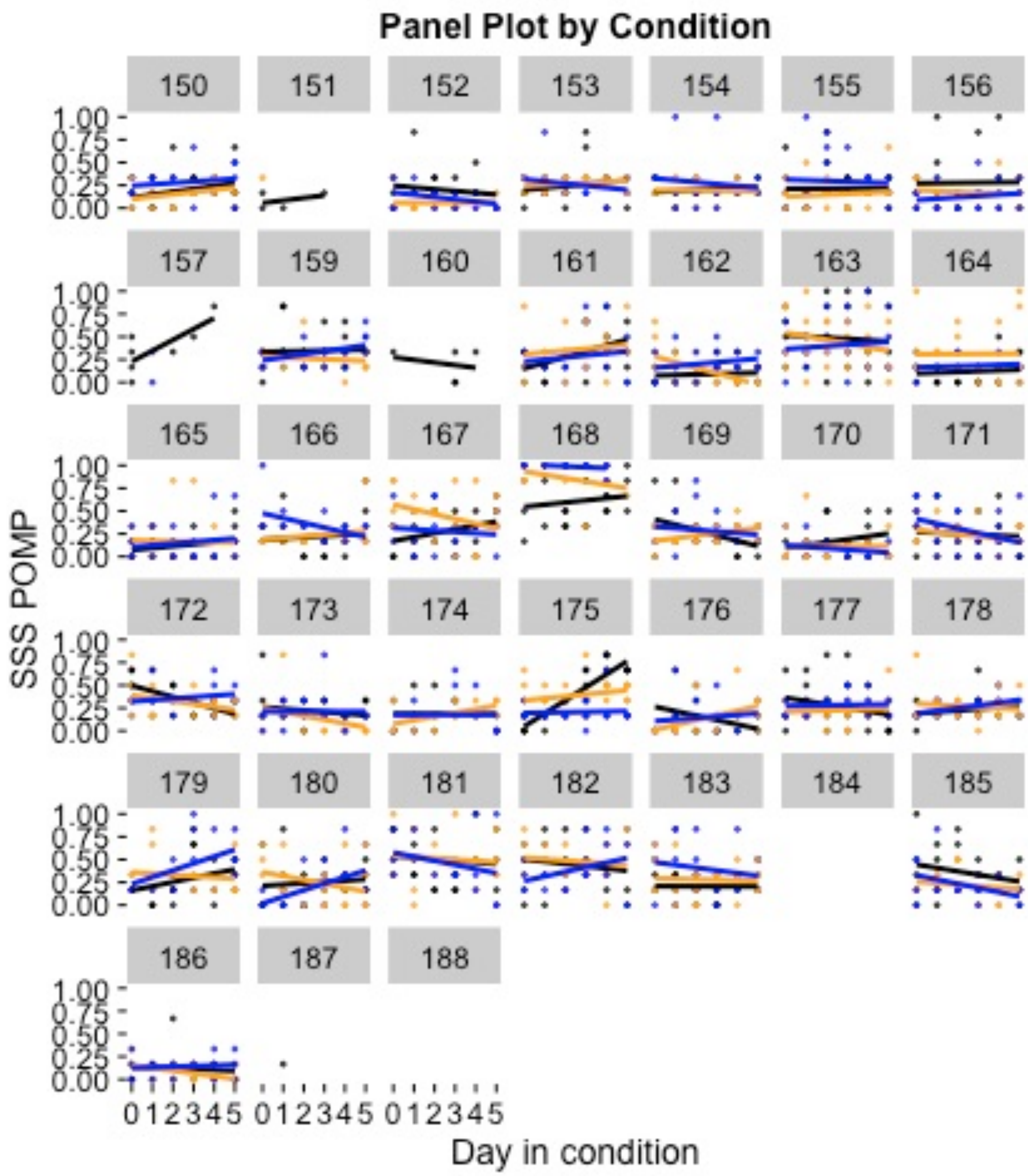

Figure 10. Panel plot of individual data for scores on the Stanford Sleepiness Scale

Table 5.

Beta Weights for Model Predicting Stanford Sleepiness Scale POMP Scores

Predictor	*ß*	*S.E.*	*DF*	*t*	*p*
Intercept	.22	.05	1924	4.08	<.0001
Amber condition (0,1)	.07	.04	1924	1.94	.05
Blue condition (0, 1)	.10	.03	1924	2.91	.003
Day in condition (0,6)	-.01	.01	1924	-1.30	.19
SMEQ POMP	.003	.01	34	.54	.59
Morning (1) vs. nonmorning (0)	-.03	.03	1924	-1.15	.25
Amber condition * morning	-.02	.03	1924	-.97	.33
Blue condition * morning	-.05	.03	1924	-1.84	.07
SMEQ POMP * morning	.002	.002	1924	1.00	.32
Amber condition * day in condition	-.02	.01	1924	-2.23	.03
Blue condition * day in condition	-.005	.01	1924	-.69	.49
Day in condition * SMEQ POMP	.002	.001	1924	2.91	.004
Amber condition * SMEQ POMP	-.003	.003	1924	-.86	.39
Blue condition * SMEQ POMP	-.01	.003	1924	-2.42	.02

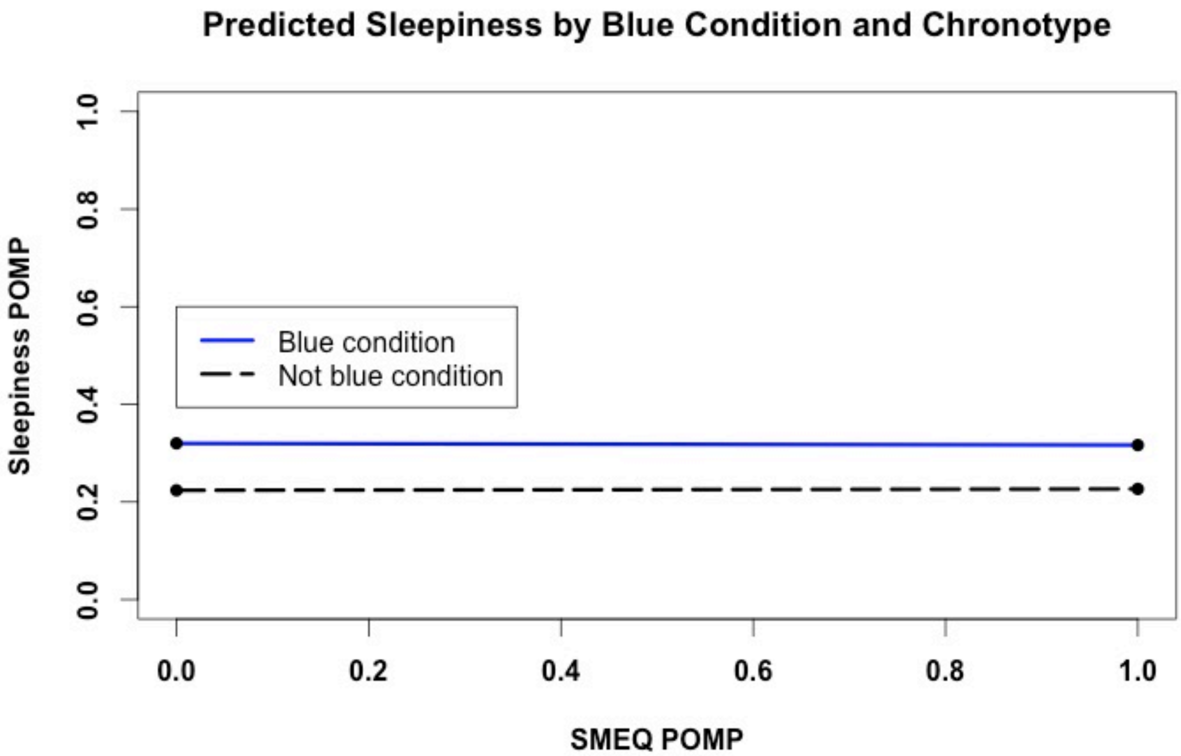

Figure 11. Interaction between blue condition (yes/no) and chronotype on ratings on the Stanford Sleepiness Scale.

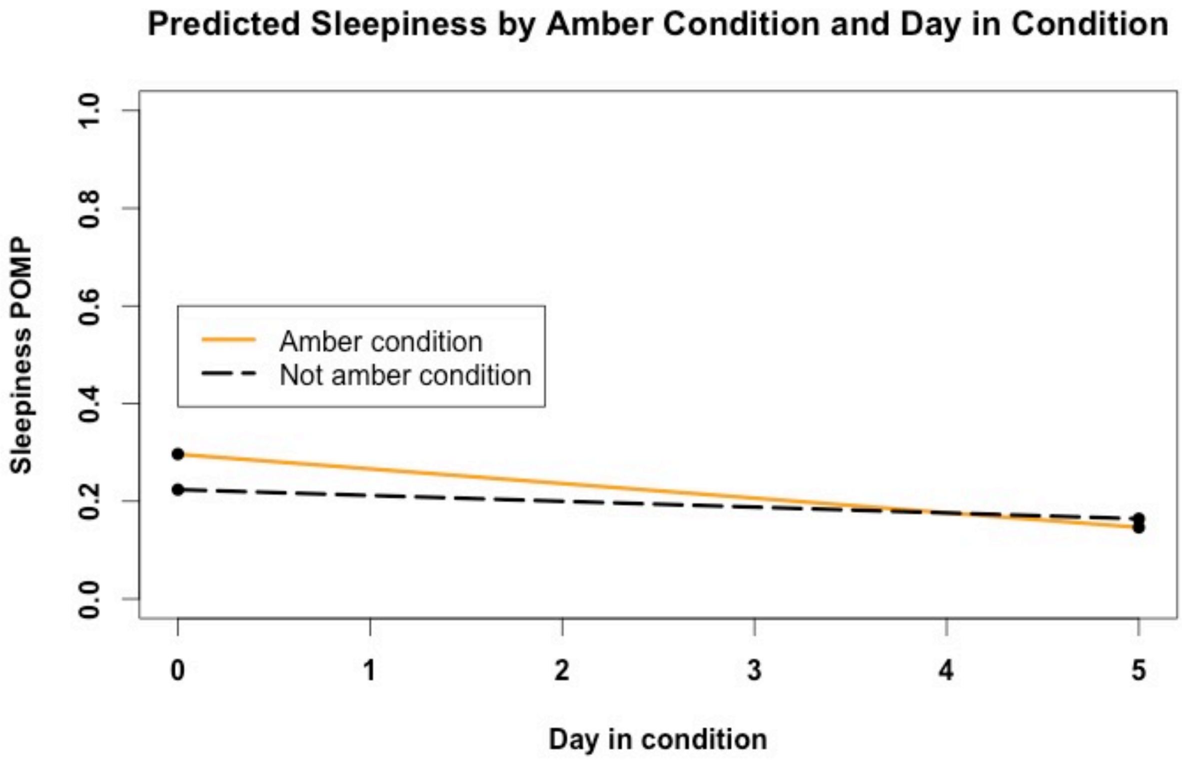

Figure 12. Interaction between amber condition (yes/no) and day in condition on ratings on the Stanford Sleepiness Scale.

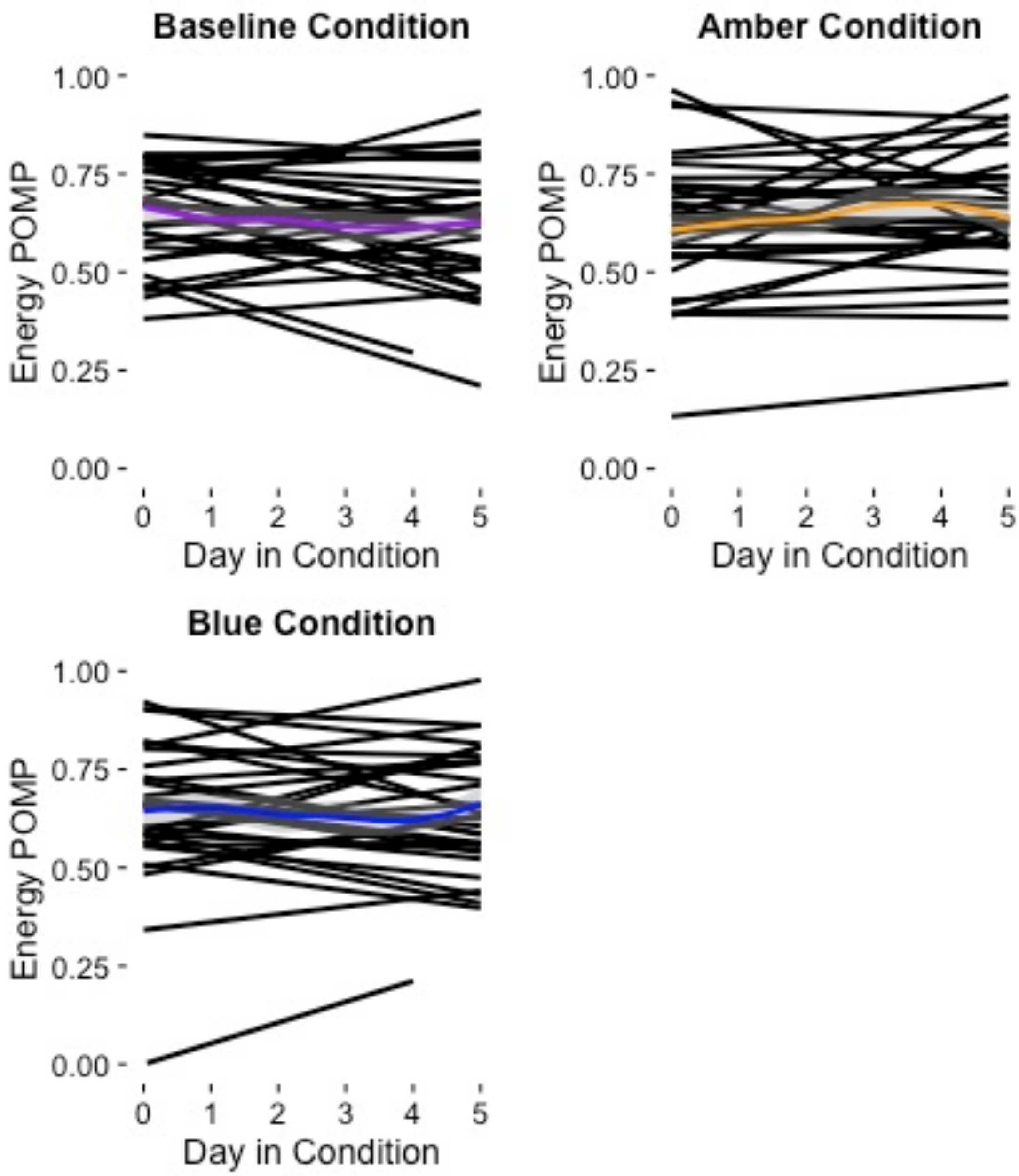

Figure 13. Spaghetti plot of linear trends within person for energy level, split by glasses color.

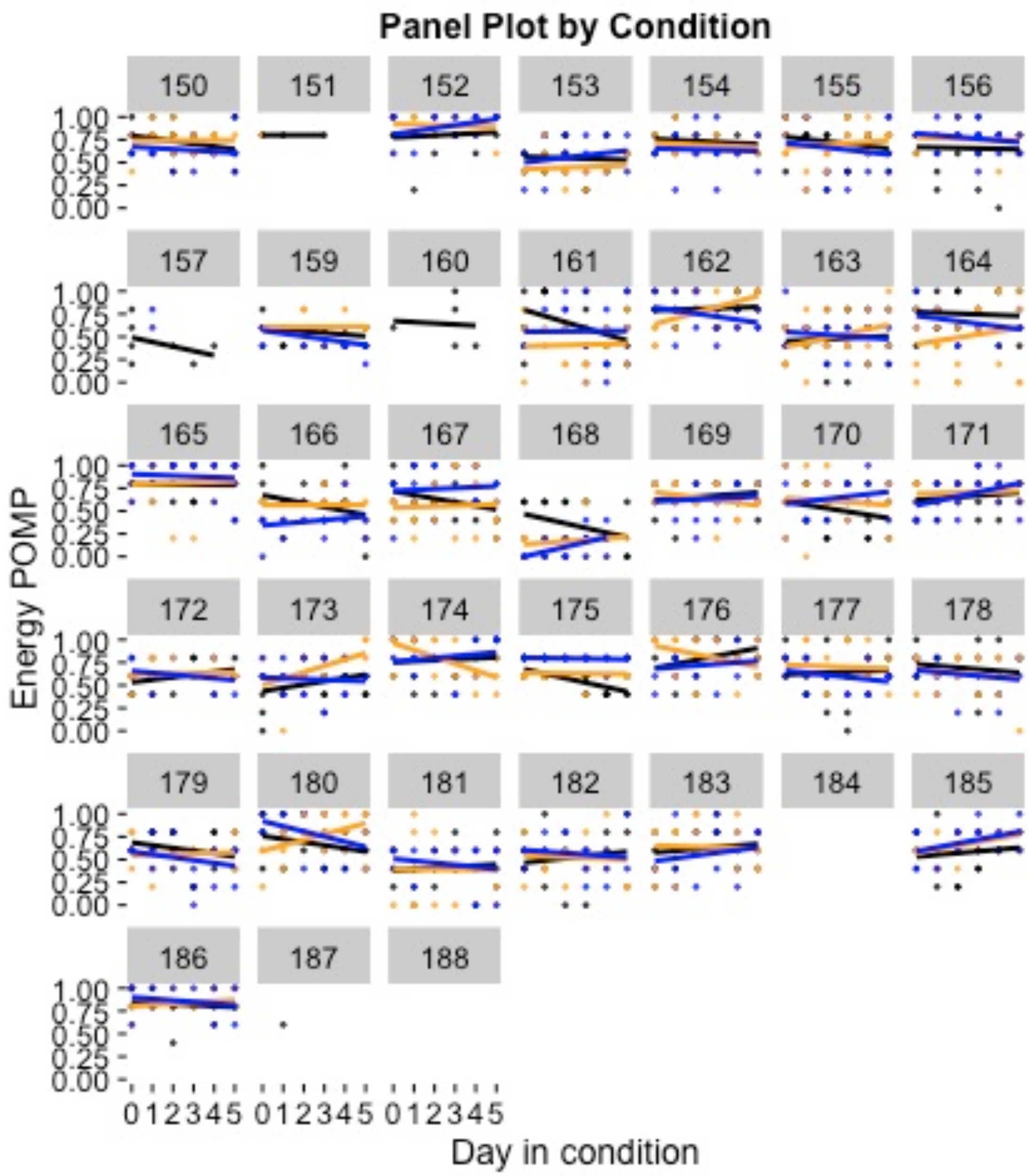

Figure 14. Panel plot of individual data for energy level.

Table 6.

Beta Weights for Model Predicting Energy POMP Scores

Predictor	*ß*	*S.E.*	*DF*	*t*	*p*
Intercept	.69	.06	1921	12.49	<.0001
Amber condition (0,1)	-.09	.04	1921	-2.24	.03
Blue condition (0, 1)	-.07	.03	1921	-2.26	.02
Day in condition (0,6)	.003	.01	1921	.34	.74
SMEQ POMP	-.005	.01	34	-.93	.36
Morning (1) vs. nonmorning (0)	.04	.03	1921	1.56	.12
Amber condition * morning	.01	.03	1921	.59	.56
Blue condition * morning	.04	.03	1921	1.69	.09
SMEQ POMP * morning	-.003	.002	1921	-1.30	.19
Amber condition * day in condition	.01	.01	1921	2.18	.03
Blue condition * day in condition	.01	.01	1921	.76	.45
Day in condition * SMEQ POMP	-.001	.001	1921	-1.84	.07
Amber condition * SMEQ POMP	.01	.003	1921	1.60	.11
Blue condition * SMEQ POMP	.01	.003	1921	2.29	.02

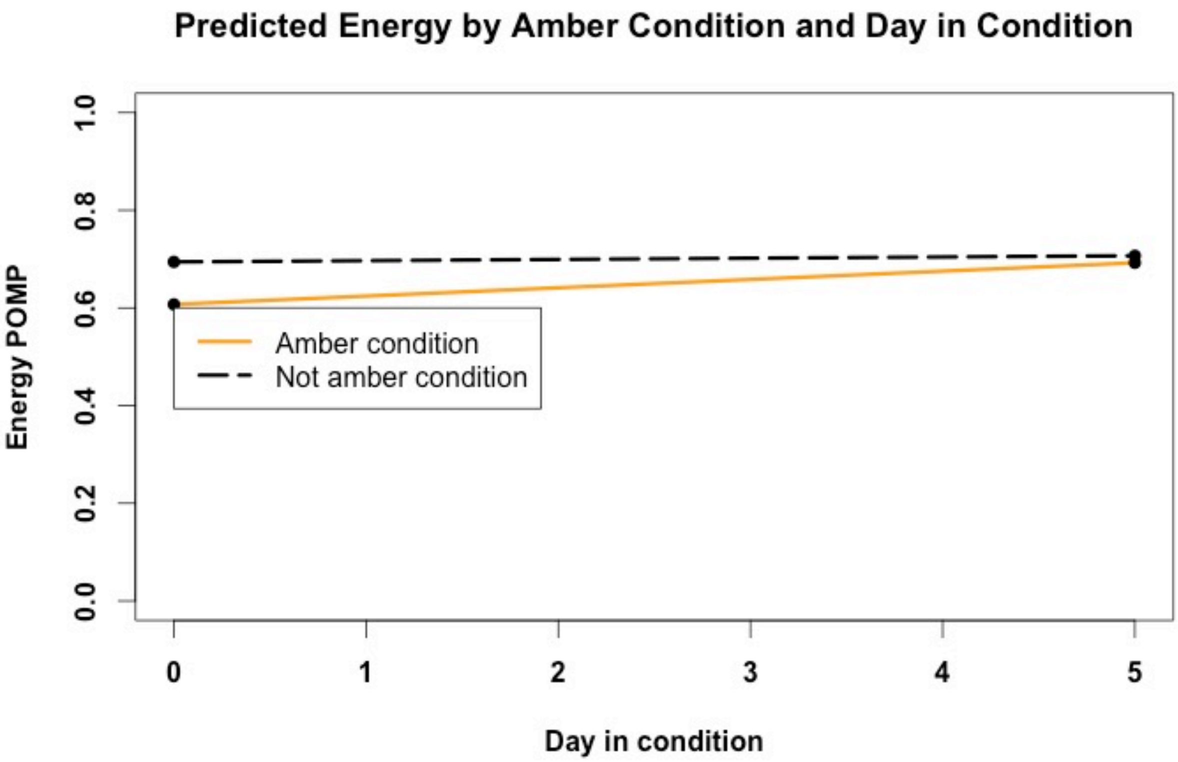

Figure 15. Interaction between amber condition (yes/no) and day in condition on energy level ratings.

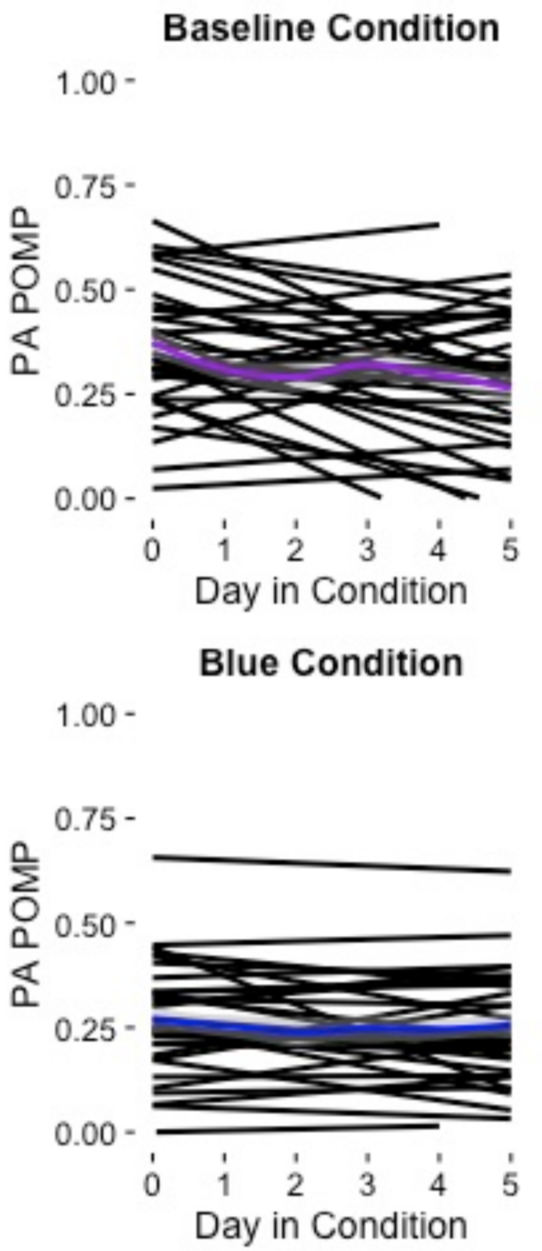

Figure 16. Spaghetti plot of linear trends within person for positive affect, split by glasses condition.

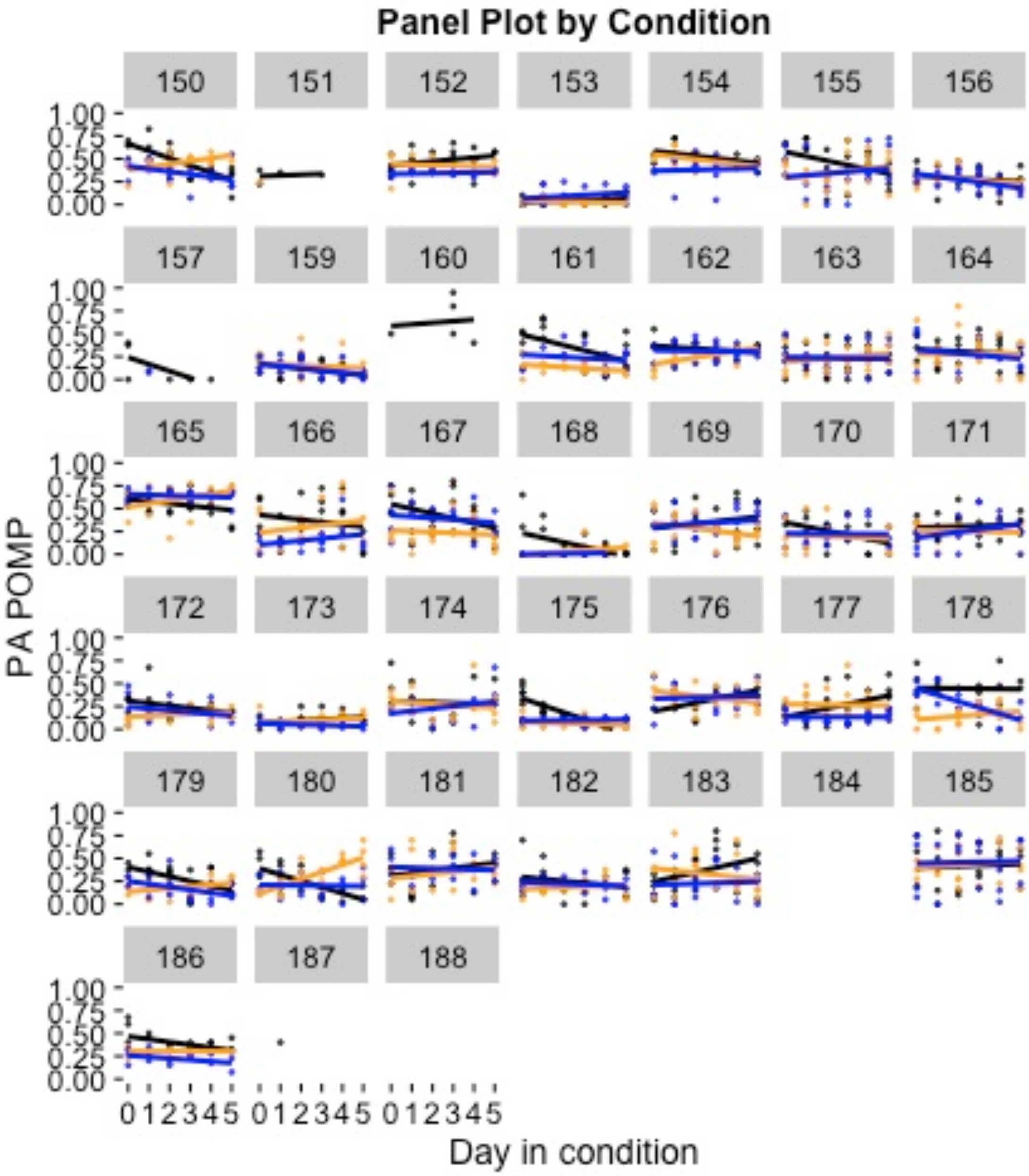

Figure 17. Panel plot of individual data for positive affect.

Table 7.

Beta Weights for Model Predicting Positive Affect POMP Scores

Predictor	*ß*	*S.E.*	*DF*	*t*	*p*
Intercept	.41	.05	1883	7.71	<.0001
Amber condition (0,1)	-.12	.03	1883	-3.62	.0003
Blue condition (0, 1)	-.07	.02	1883	-3.02	.003
Day in condition (0,6)	-.02	.01	1883	-2.82	.005
SMEQ POMP	-.01	.005	34	-1.22	.23
Morning (1) vs. nonmorning (0)	.04	.02	1883	2.20	.03
Amber condition * morning	-.02	.02	1883	-1.34	.18
Blue condition * morning	.02	.02	1883	1.11	.27
SMEQ POMP * morning	-.002	.002	1883	-1.29	.20
Amber condition * day in condition	.02	.005	1883	4.89	<.0001
Blue condition * day in condition	.01	.005	1883	2.77	.01
Day in condition * SMEQ POMP	-.0002	.0004	1883	-.54	.59
Amber condition * SMEQ POMP	.002	.003	1883	.62	.53
Blue condition * SMEQ POMP	-.002	.002	1883	-1.12	.26

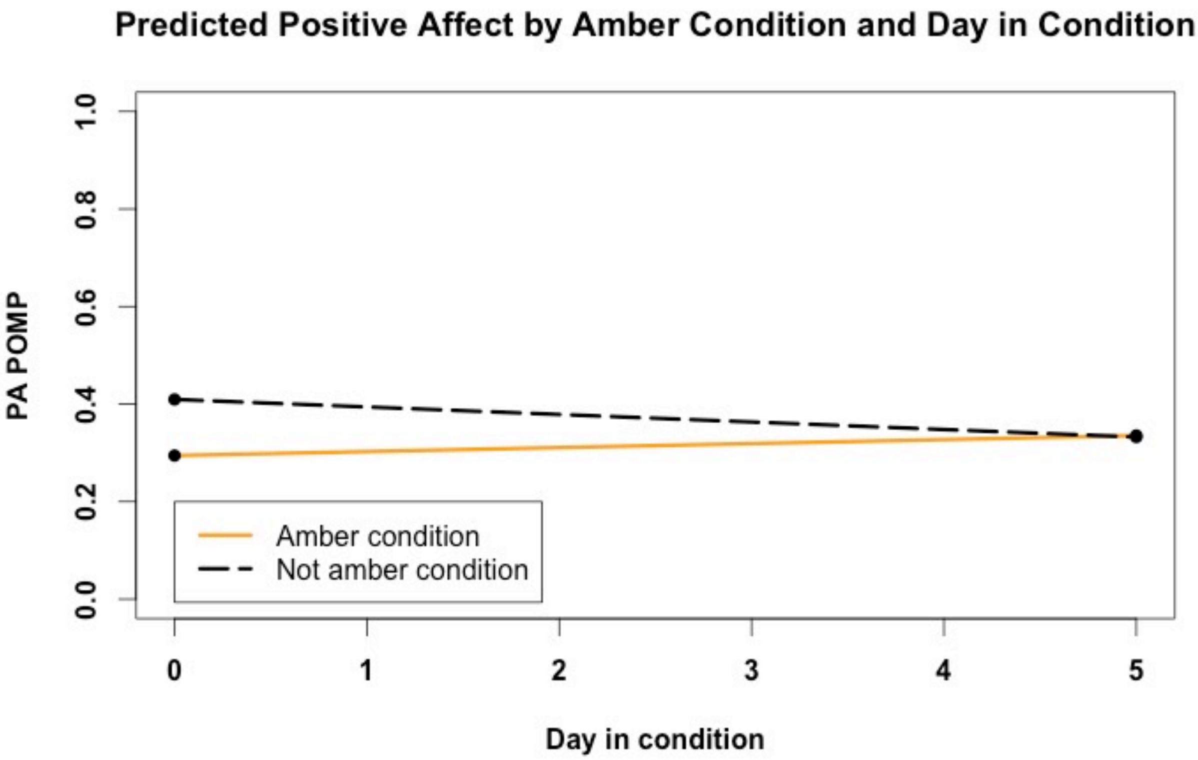

Figure 18. Interaction between amber condition (yes/no) and day in condition on positive affect ratings.

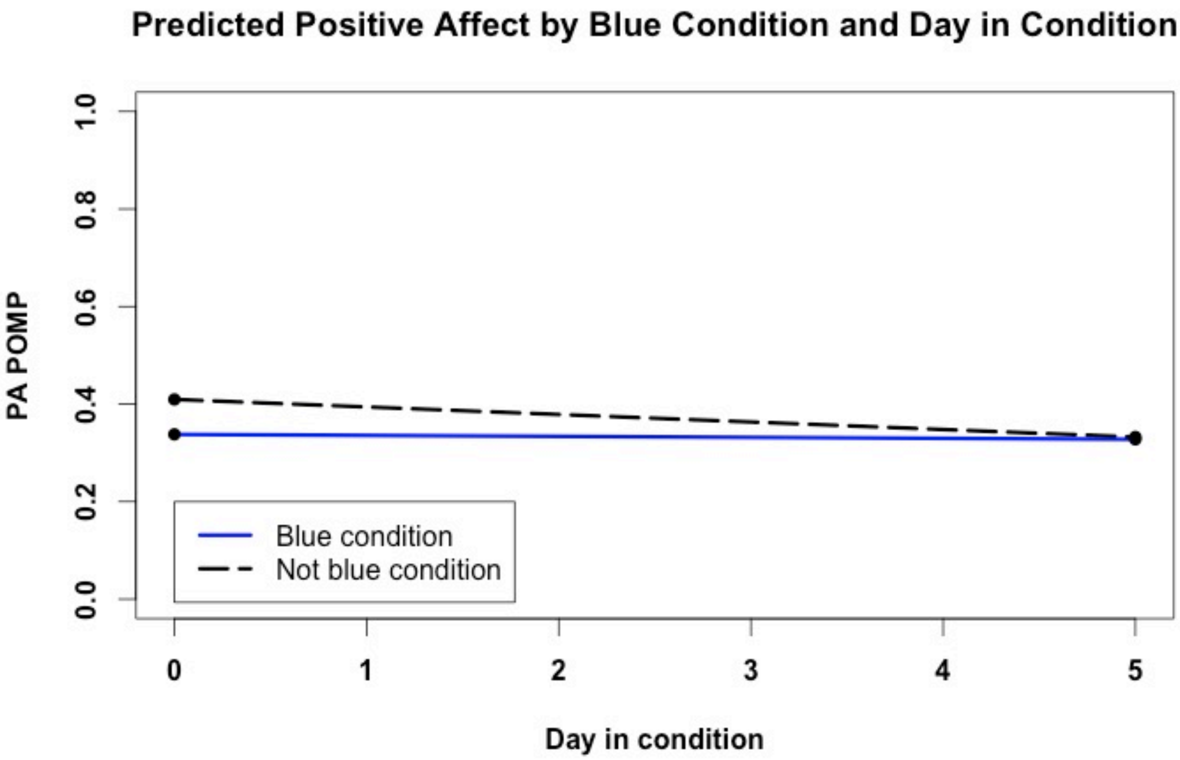

Figure 19. Interaction between blue condition (yes/no) and day in condition on positive affect ratings.

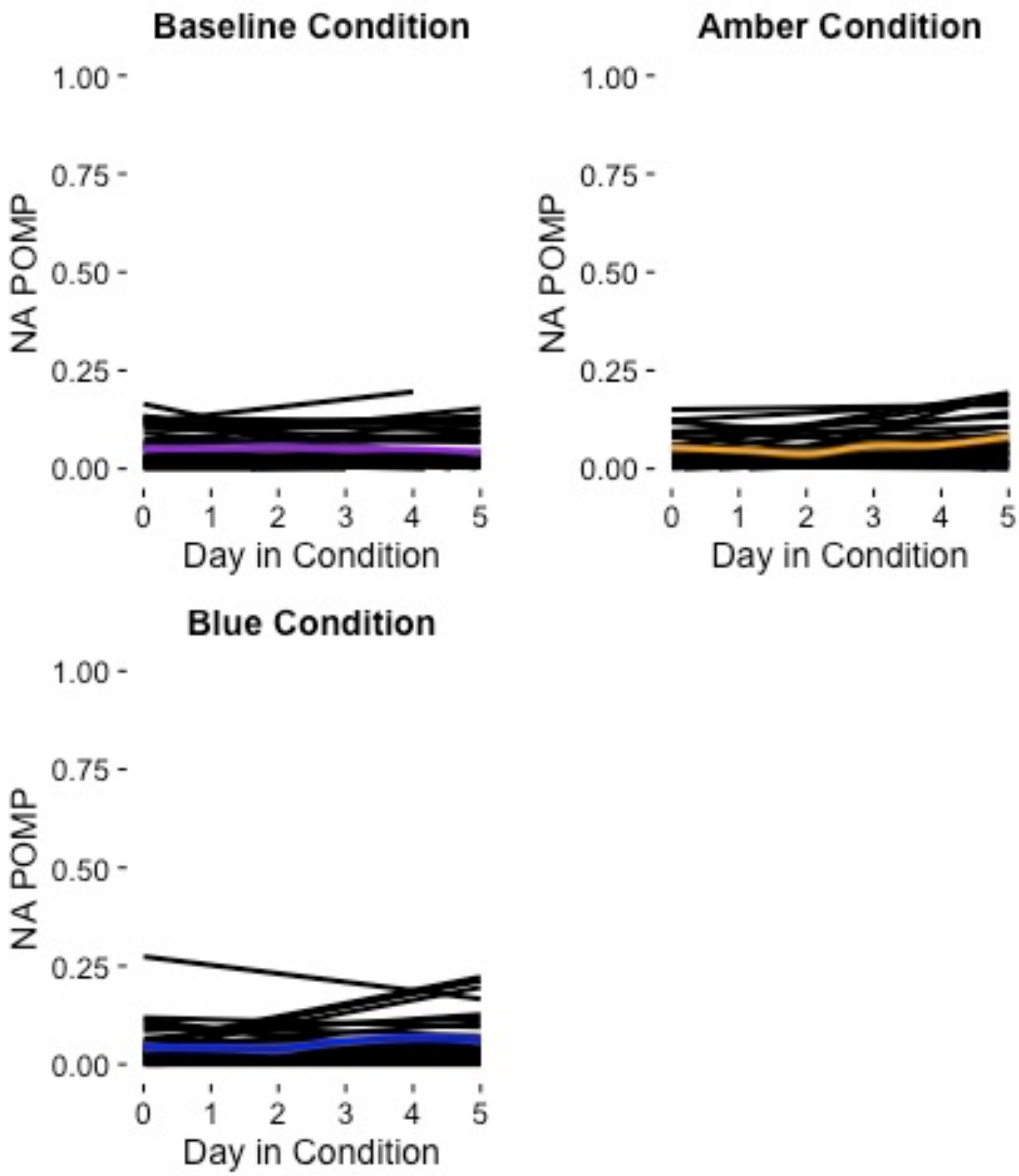

Figure 20. Spaghetti plot of linear trends within person for negative affect ratings, split by glasses condition.

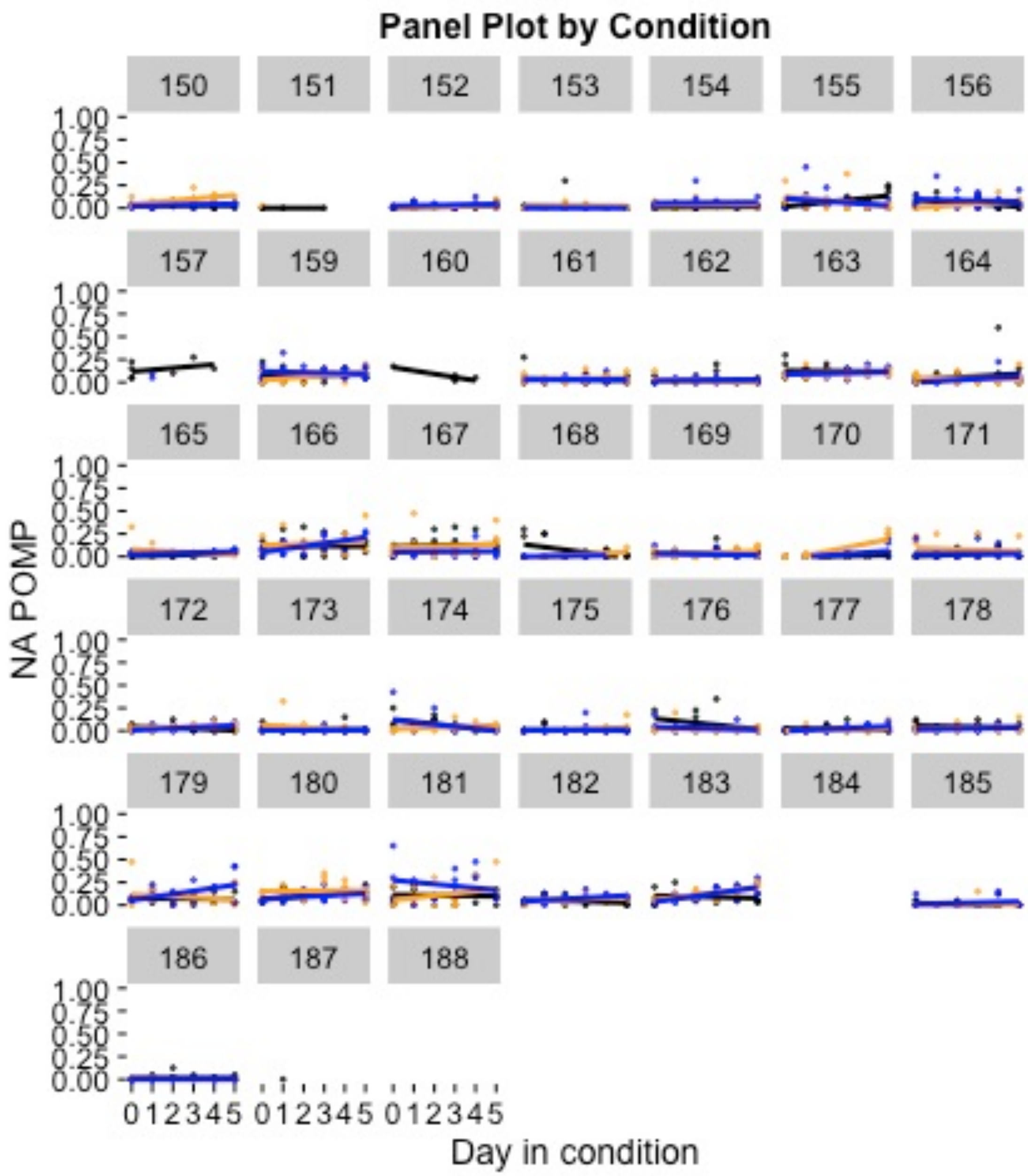

Figure 21. Panel plot of individual data for negative affect ratings.

Table 8.

Beta Weights for Model Predicting Negative Affect POMP Scores

Predictor	*ß*	*S.E.*	*DF*	*t*	*p*
Intercept	.04	.02	1889	2.05	.04
Amber condition (0,1)	-.01	.01	1889	-.72	.47
Blue condition (0, 1)	-.01	.01	1889	-.90	.37
Day in condition (0,6)	-.002	.002	1889	-.63	.53
SMEQ POMP	.002	.002	34	.98	.33
Morning (1) vs. nonmorning (0)	.005	.009	1889	.50	.61
Amber condition * morning	-.009	.008	1889	-1.06	.29
Blue condition * morning	-.009	.008	1889	-1.10	.27
SMEQ POMP * morning	-0.00004	.0007	1889	-.06	.95
Amber condition * day in condition	.005	.002	1889	2.56	.01
Blue condition * day in condition	.005	.002	1889	2.45	.01
Day in condition * SMEQ POMP	.0001	.0002	1889	.55	.59
Amber condition * SMEQ POMP	.0003	.001	1889	.27	.79
Blue condition * SMEQ POMP	.0002	.001	1889	.23	.82

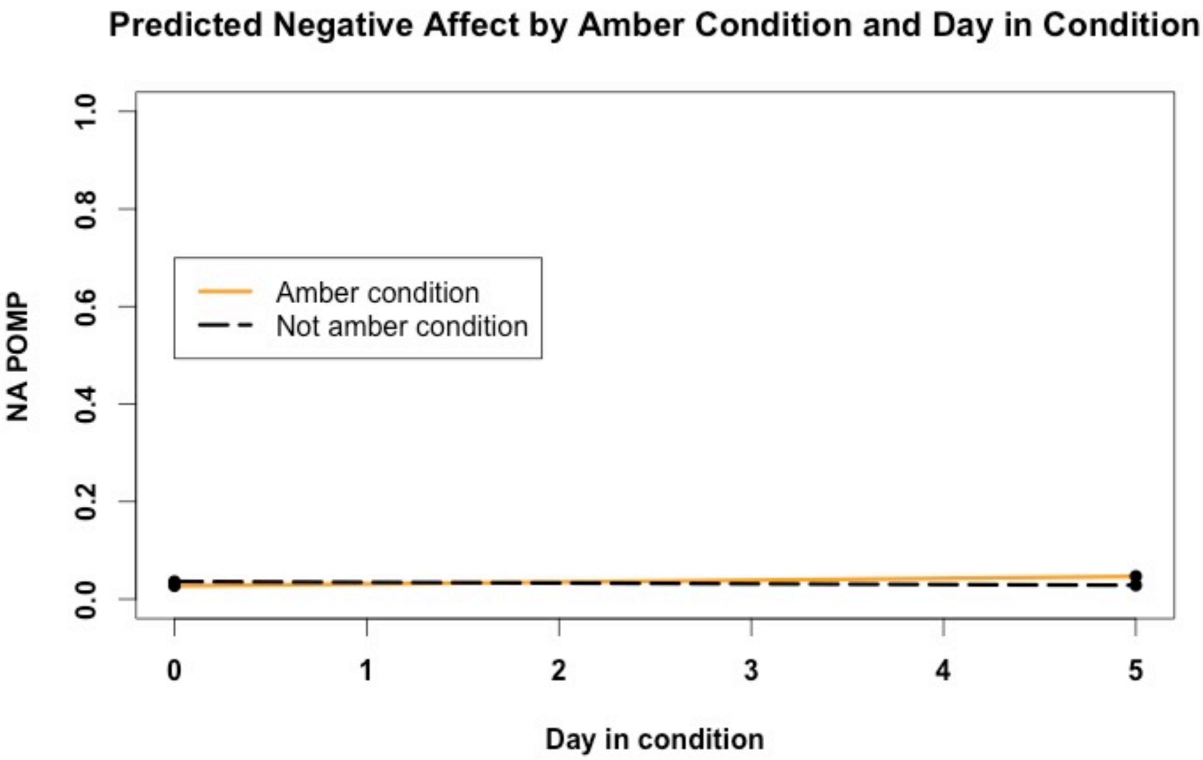

Figure 22. Interaction between amber condition (yes/no) and day in condition on negative affect ratings.

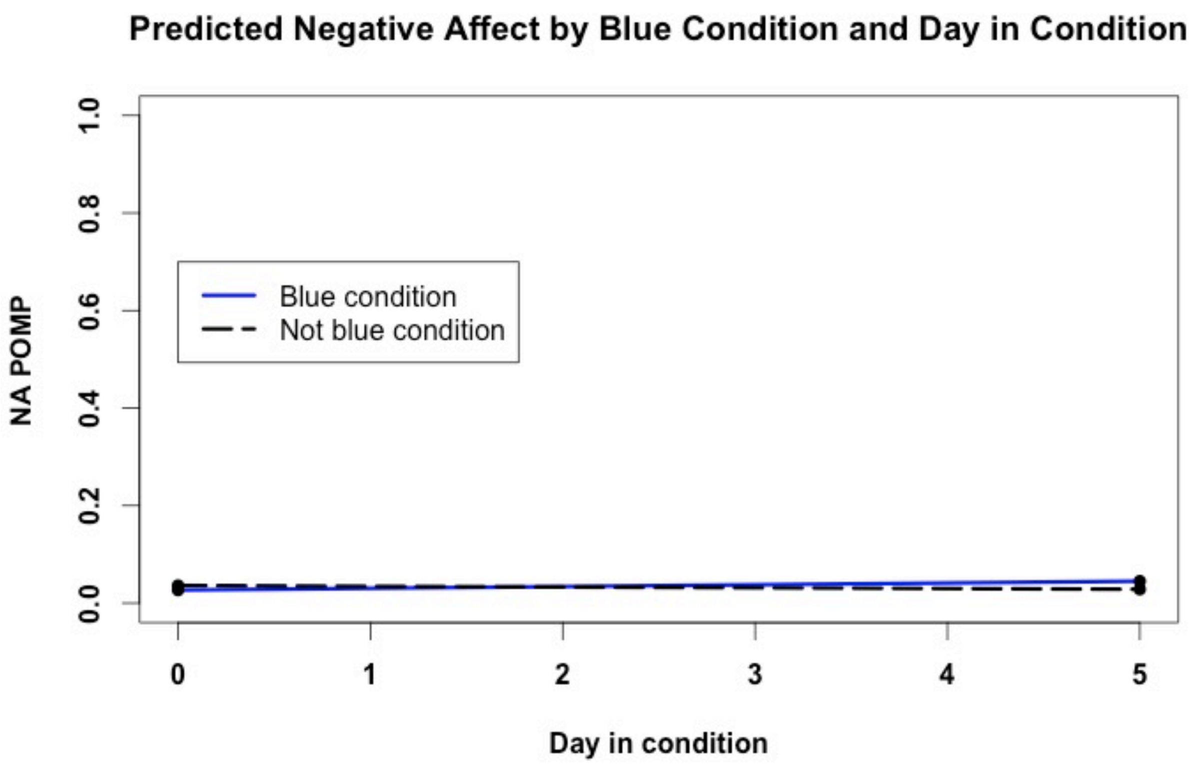

Figure 23. Interaction between blue condition (yes/no) and day in condition on negative affect ratings.